CloudSat and GPM: exploiting the synergy

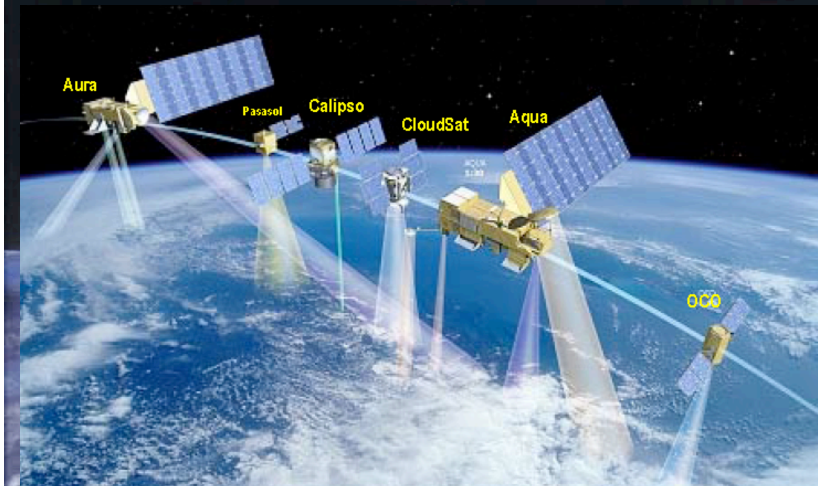
Graeme Stephens

6th GPM planning meeting Nov, 2006

Can a cloud mission (ie. CloudSat), that ‘does a little precipitation’, significantly contribute toward the aspirations of a precipitation mission, that ‘does a little cloud’ ????

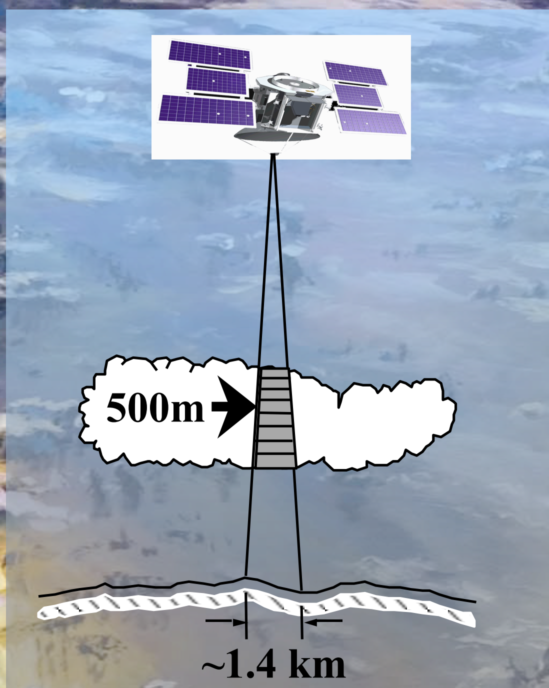
YES and furthermore there are exciting opportunities and mutual benefits to be gained

Two components to the mission design



1. Formation with the A-Train -sun sync, polar orbit, CloudSat and AMSR-E

2. The Cloud Profiling Radar (CPR)



- Nadir pointing, 94 GHz radar
- 3.3μs pulse ➔ 500m vertical res, over- sampled at ~240m
- 1.4 km horizontal res.
- Sensitivity ~ -28 dBZ (-30 to -32 dBZ?)
- Dynamic Range: 80 dB

The CloudSat Mission

Primary Objective: To provide, from space, the first global survey of **cloud (& precip)** profiles and **cloud** physical properties, with seasonal and geographical variations needed to evaluate the way **clouds** (& precip) are parameterized in global models, thereby contributing to weather predictions, climate and the **cloud**-climate feedback problem.

Key highlights:

Launched on April 28th

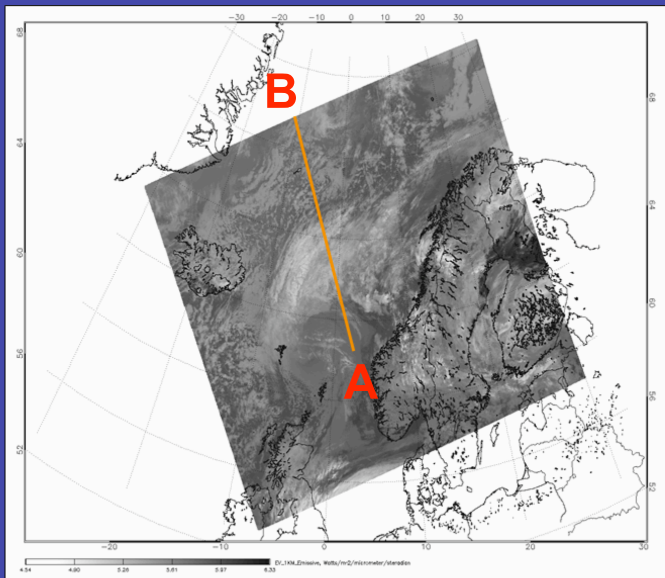
Instrument turn on May 20th (4 hour test) & operations began June 2

Calibration activities - ocean views & sfc, aircraft val experiments have confirmed radar performance

Since launch, we have ~70 passes over tropical cyclones and 5 passes through the eye of the storms

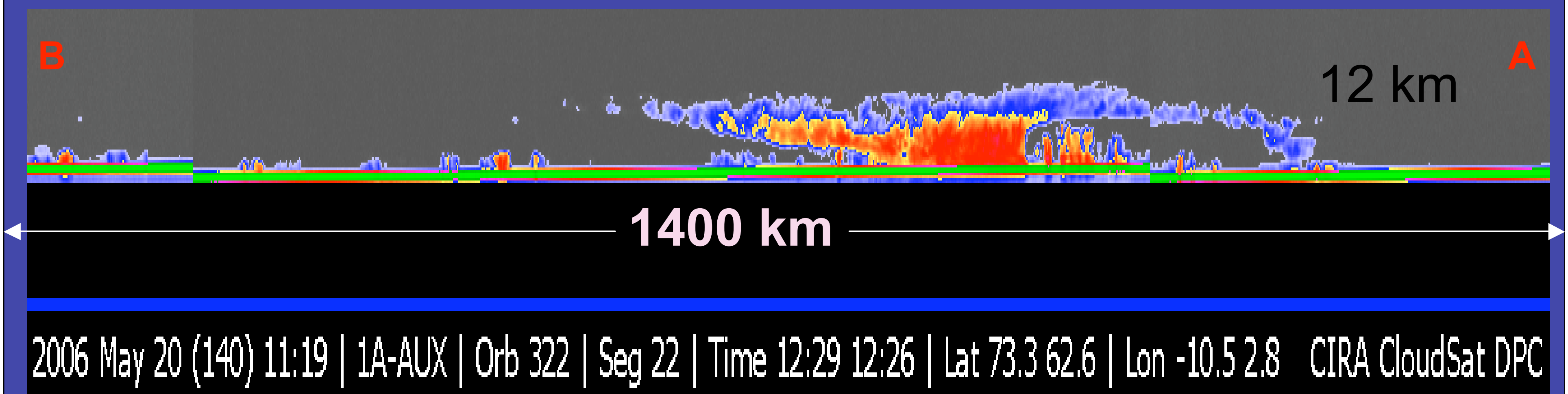
CloudSat - FIRST IMAGE

This segment was the first dump of CloudSat data - 20 May 2006 12:26-12:29 UTC



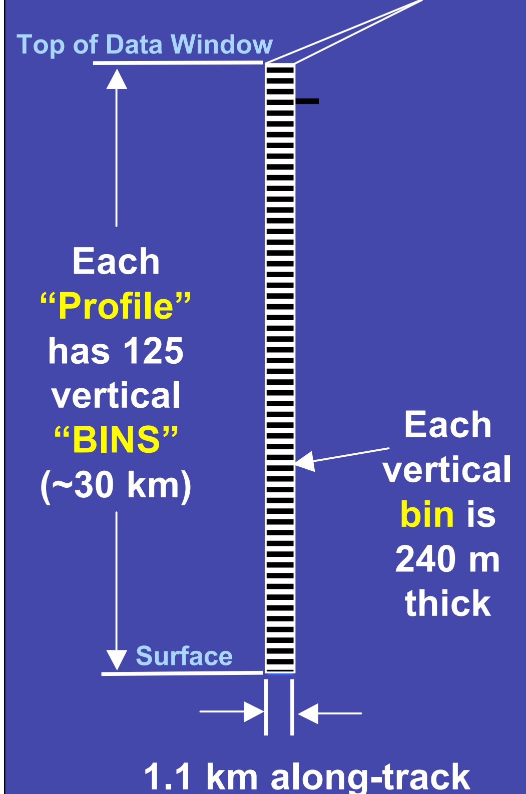
Location of CloudSat data segment on a 5-minute MODIS infrared (10.8μ) data swath.
(approx. 25 minutes prior to CloudSat overpass)

(MODIS image downloaded from Goddard DAAC)

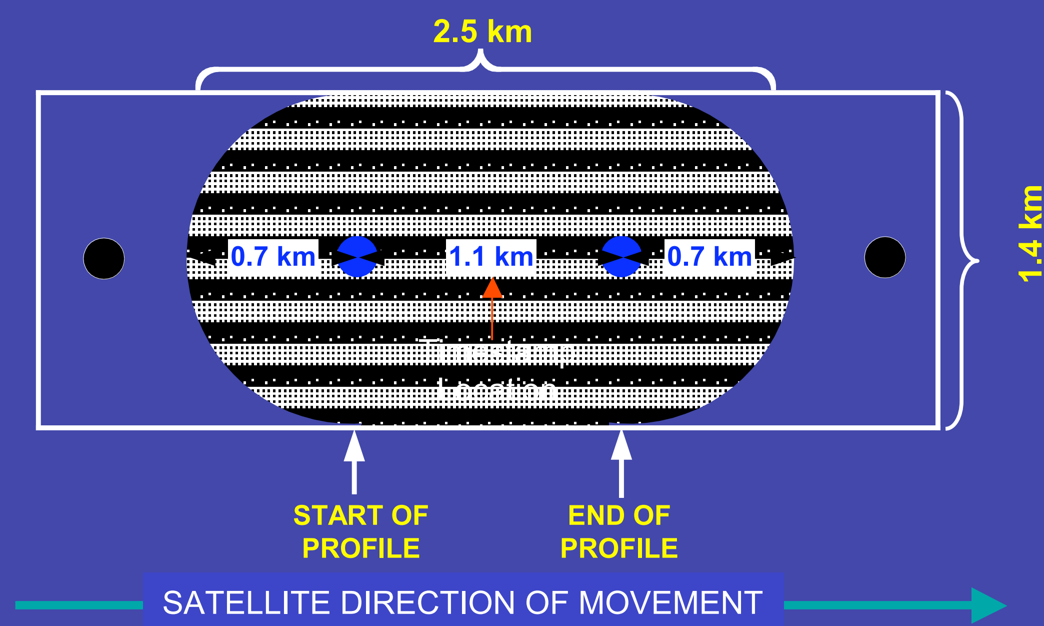


CloudSat DPC: CPR footprint & granule size

1 GRANULE = 1 orbit of data (~ 40,786 km / ~ 37,088 profiles)

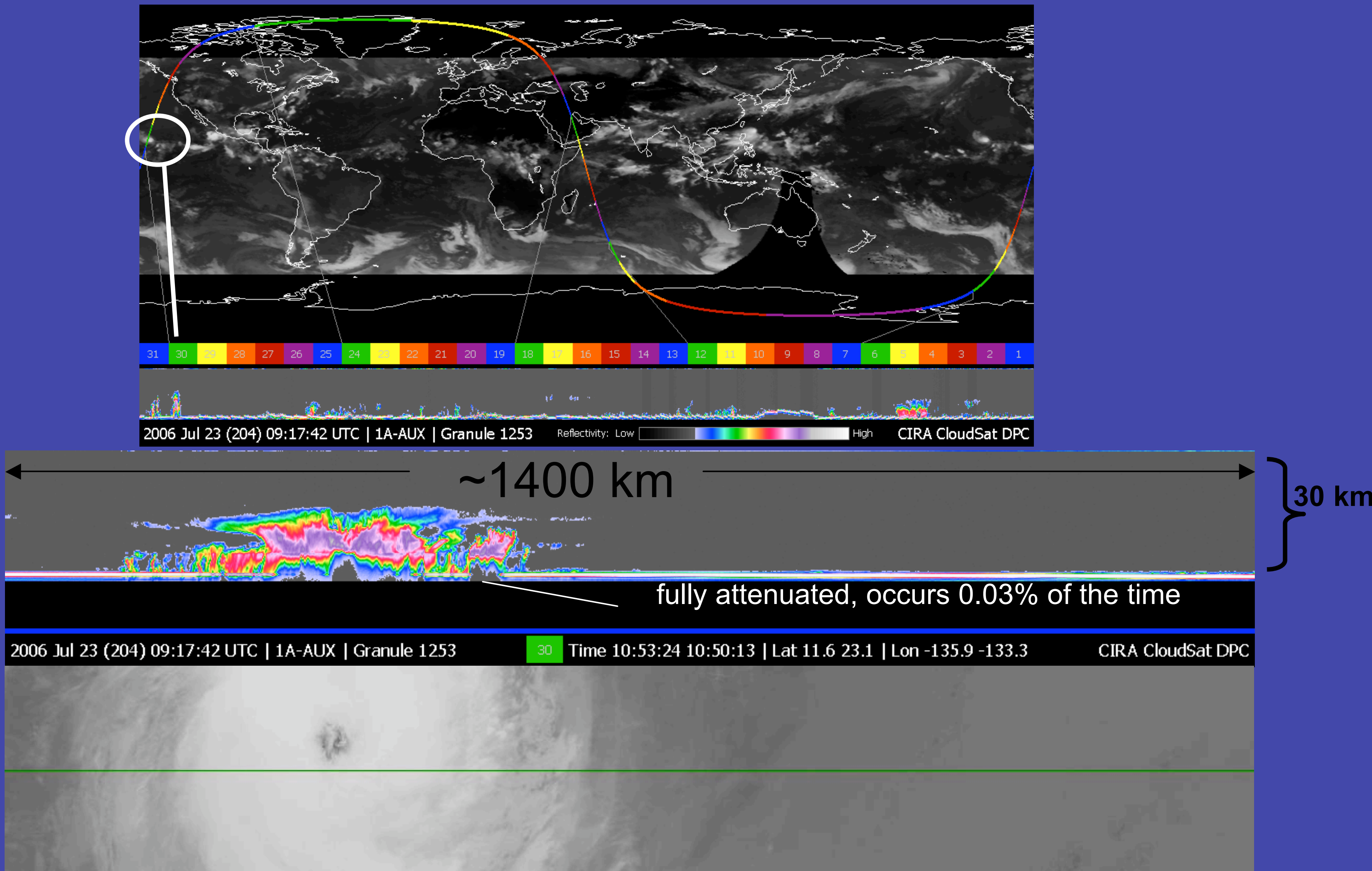


- **Granule begins on descending node (night side)**
- **"Data Window" is 30-km high by 37,088 profiles wide**



98.9 minutes per orbit 14.56 orbits/day

CloudSat - Quicklook Image _ Geo and MODIS imagery



http://www.cloudsat.cira.colostate.edu

CloudSat Data Products

- Level 0 (from RSC)

  0A-CPR – raw science data

  SSOH - stored (instrument) state-of-health data

- Level 1 (geolocation and time added to data)1A-AUX – Geolocation, time, engr. data

  1B-CPR – Calibrated CPR ±2dBZ

  1B-CPR-FL - Calibrated CPR (First Look)

- Level 2 (science data products)

  2B-GEOPROF - geometrical profile* -30 dBZ, 500m, z>1lm

  2B-CLDCLASS - cloud type classification

  2B-TAU-OFF-N - cloud optical depth (off nadir)

  2B-LWC - cloud liquid water content LWP~20%

  2B-IWC - cloud ice water content IWP ~30%

  2B-FLXHR - fluxes and heating rates

  2B-E -(Precipitation) TBD

- Level 3 (summary/statistical data products)

  Summary statistics on a global 1 degree grid

*** CloudSat also is producing a lidar-radar version of geoprof that will become available as CALIPSO data becomes available**

Cloudsat's cloud - precipitation activities

•Algorithms:

- PIA - precip occurrence, surface precip (relies on surface σ_o)
- Profile (slope) method of Matrosov (2-5km) extends precip > 10 mm/hr
- Bayesian vertical profile of precip using PIA, Z (but could add other obs) and implicitly accommodates the slope approach

•Strengths:

- CPR offers higher spatial resolution than other sensors that directly measure precipitation - very sensitive precip detector
- Sensitivity to continuum of ***clouds, drizzle, rainfall, and snowfall*** facilitates studying transition regions and fills gaps missed by both TRMM and GPM. Connecting cloud & precip is compelling

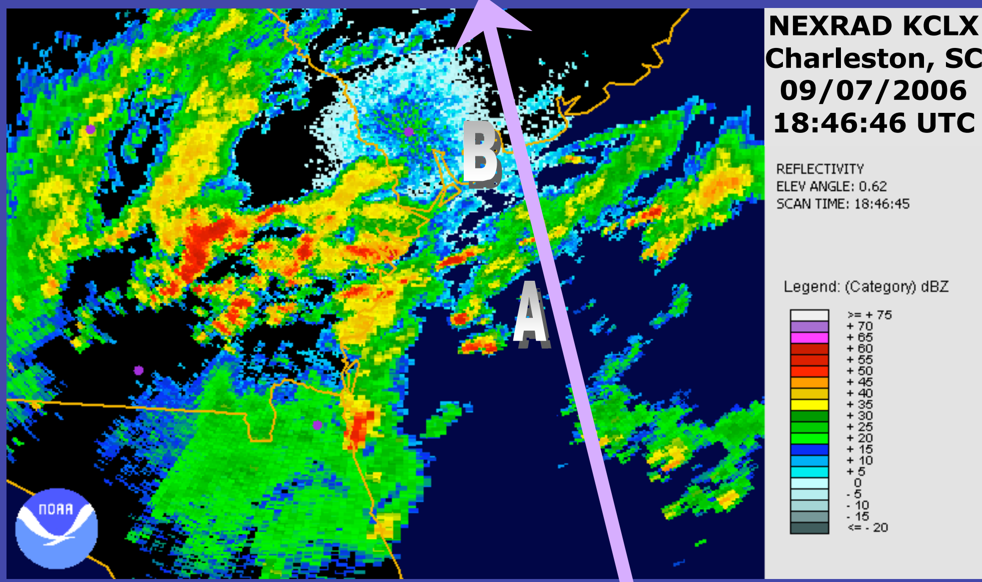
•Weaknesses:

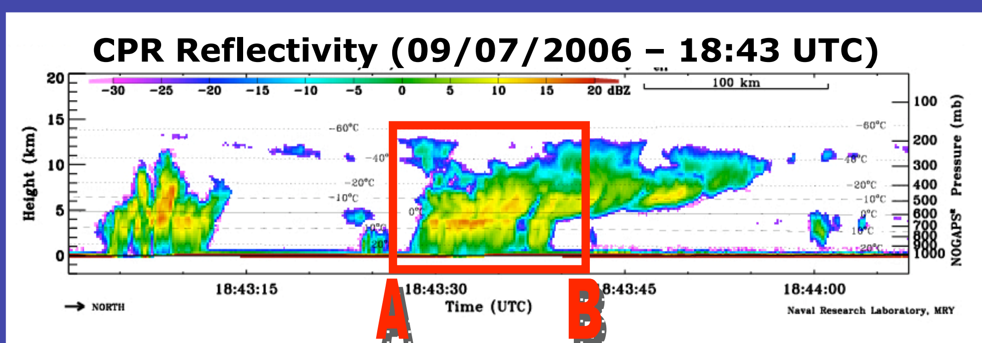
- Strong attenuation at 94 GHz limits (PIA) retrievals ≤10 mm/hr
- Single-frequency method limits information regarding the dielectric properties of the melting layer and restricts DSD assumptions
- CPR is nadir-pointing providing only a 2D slice but it is global

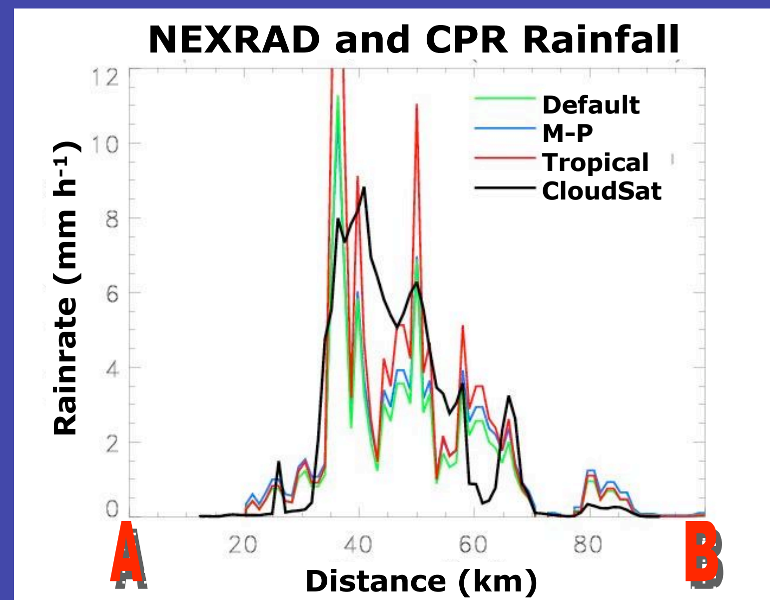
Preliminary

Profiling algorithm compared to Nexrad

CloudSat

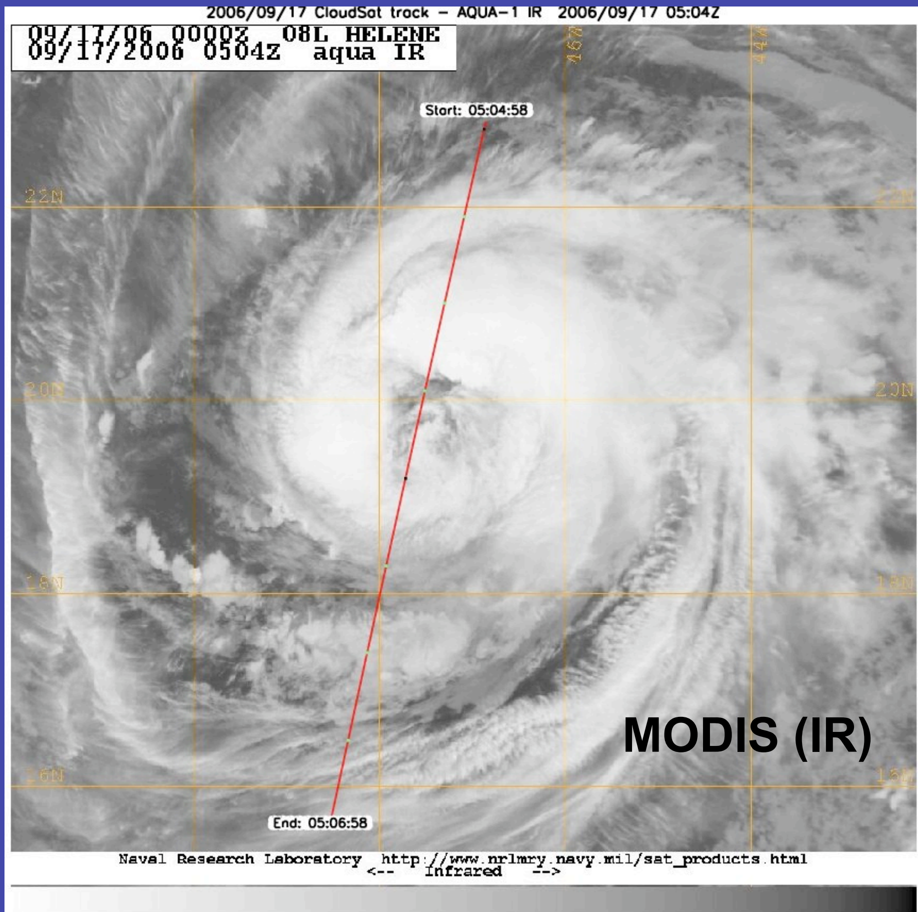


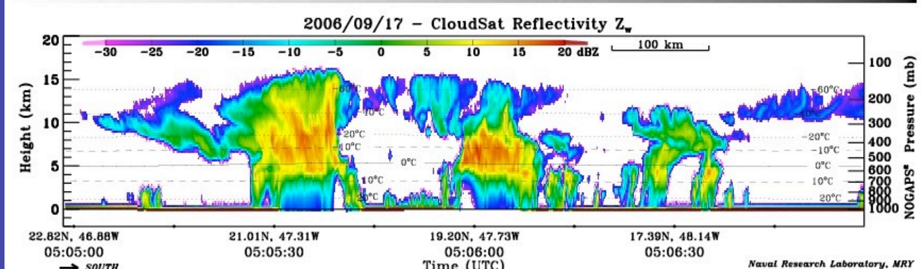


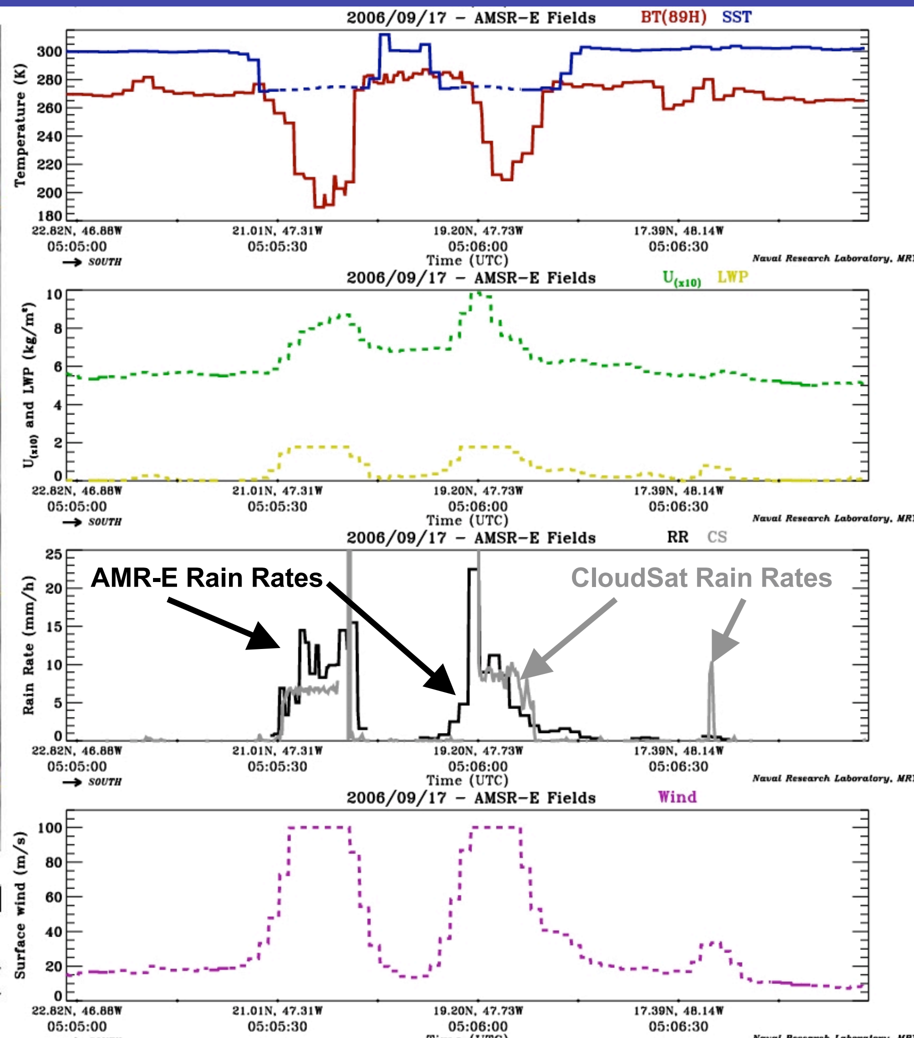


Multi-sensor validation/comparison

HURRICANE HELENE – 2006/09/17 05:04Z







AMSR-E fields along Cloudsat track

Thoughts on where CloudSat can contribute to GPM goals

Quantify effects of clouds and other factors on PMW retrievals of precip (e.g CloudSat -AMSRE comparisons)

Provide new information about global precipitation types, such as light ,extra-tropical precipitation *& snow*

Improving cloud prediction (& assimilation activities) will greatly advance precip prediction (& assimilation activities)

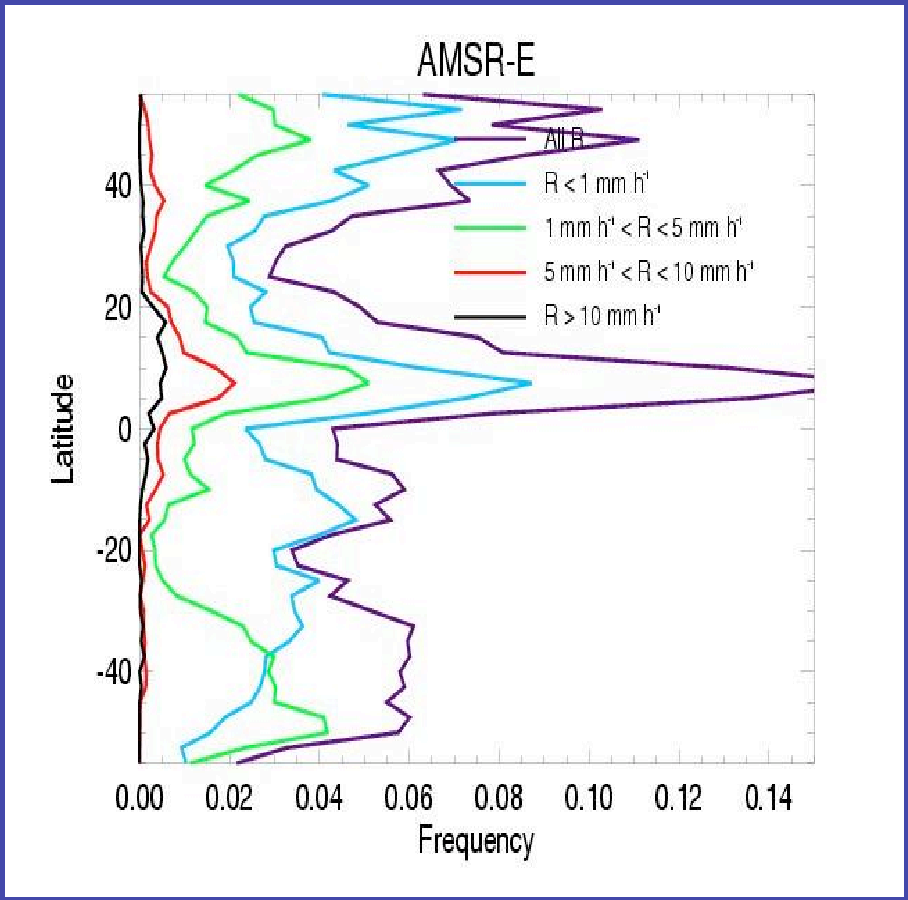
CloudSat benefits from the TRMM &GPM

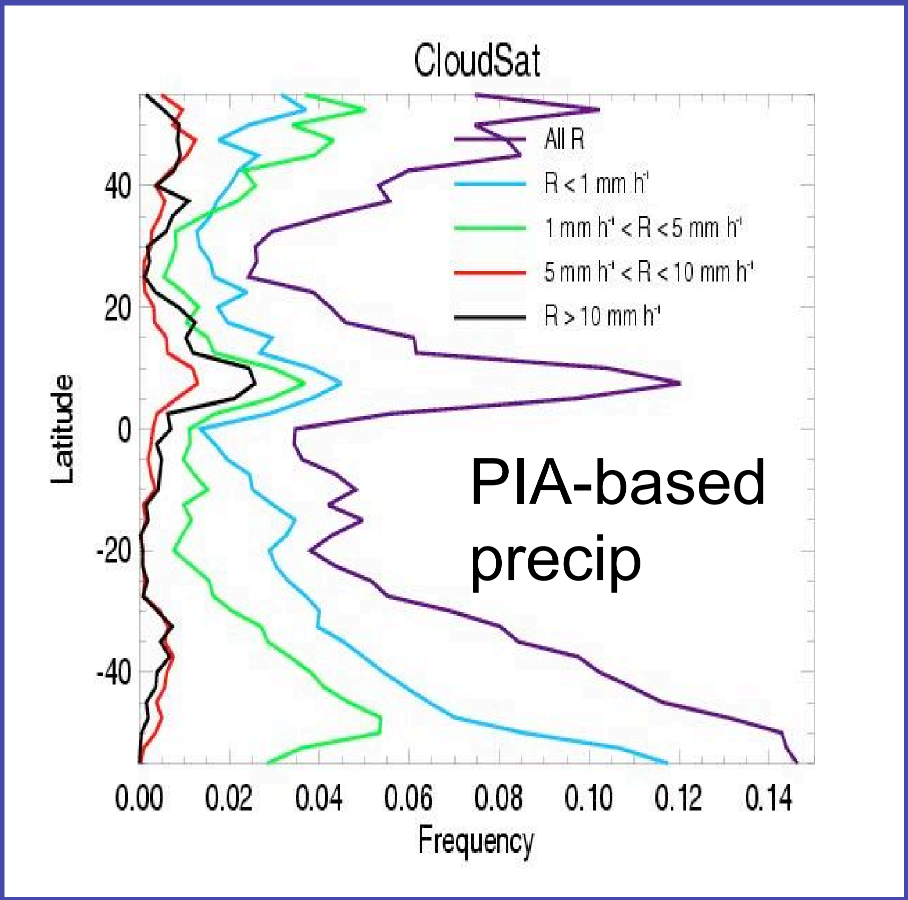
Boot-strap into extensive activities to evaluate CloudSat precip products (eg TRMM PR -CloudSat, CloudSat-AMSRE, …)

Other Areas of mutual benefit

Explicitly piggy-back on each others validation efforts (CloudSat →AMSRE Wakasa Bay expt, GPM→C3VP)

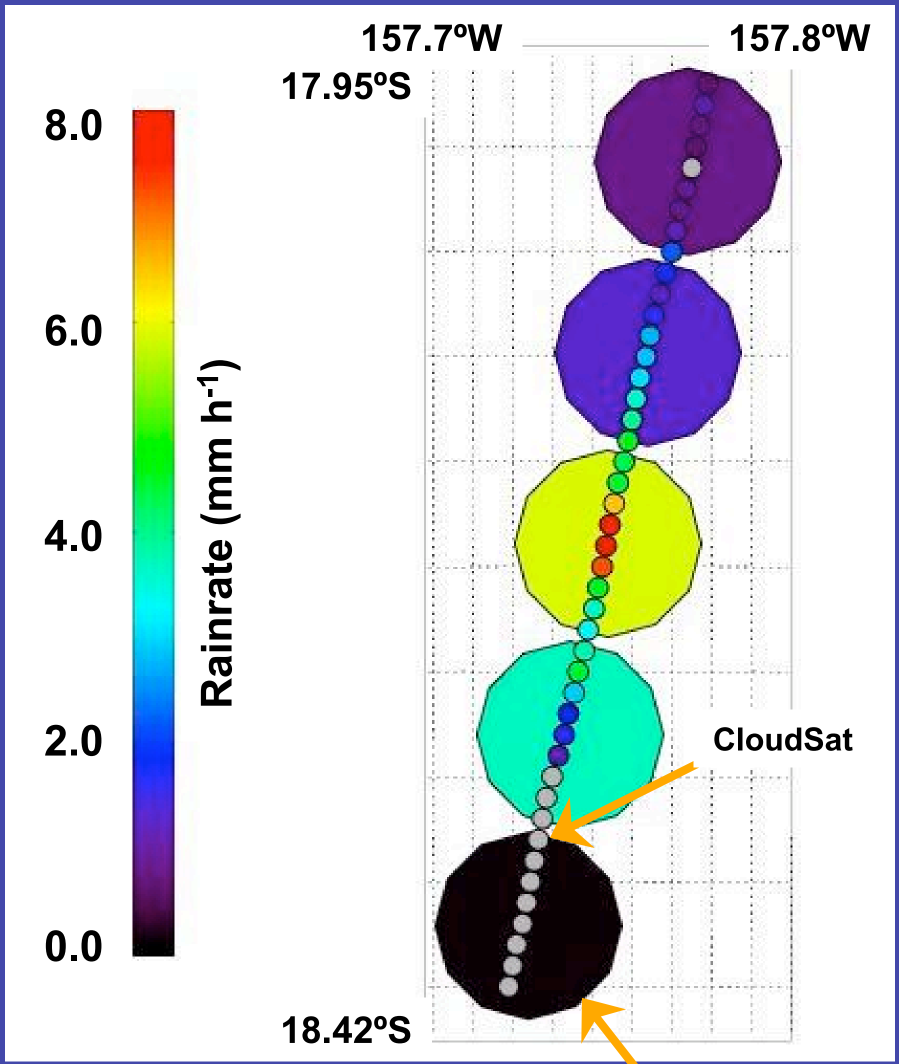
Comparison of PIA with AMSR-E

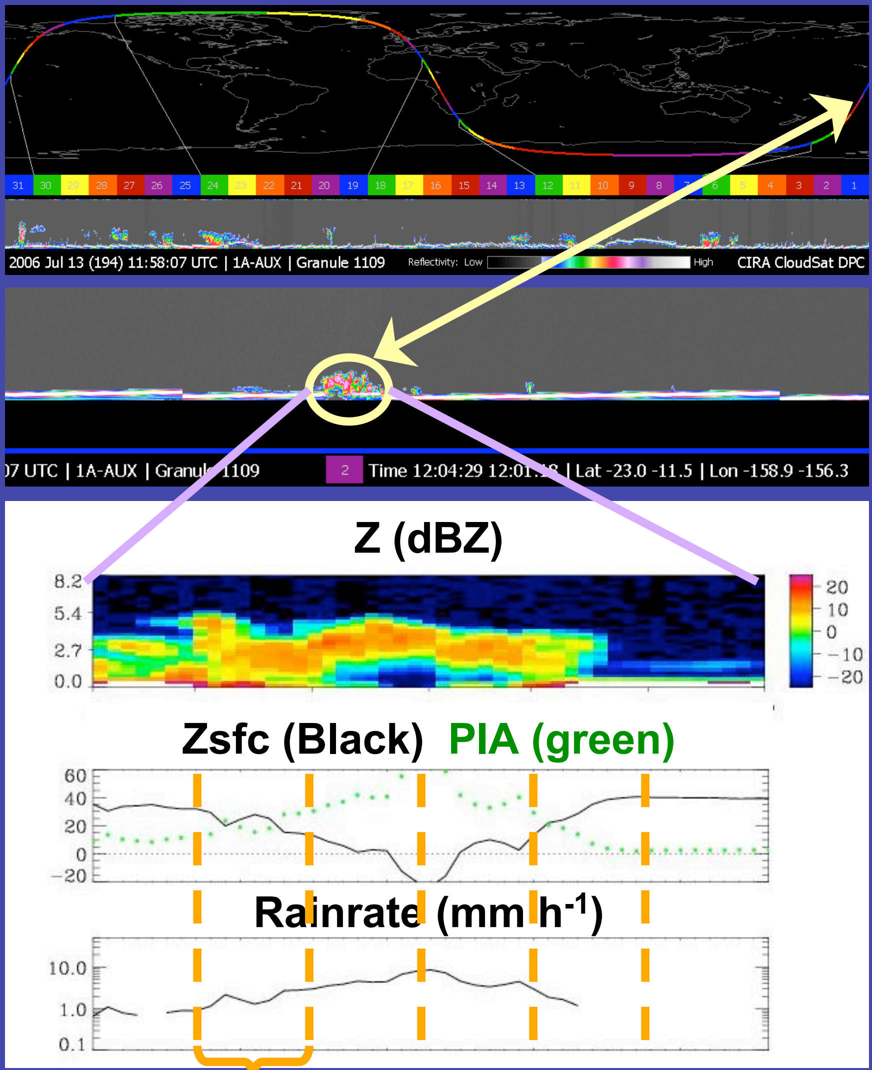




16 days of direct pixel match-ups during August 2006

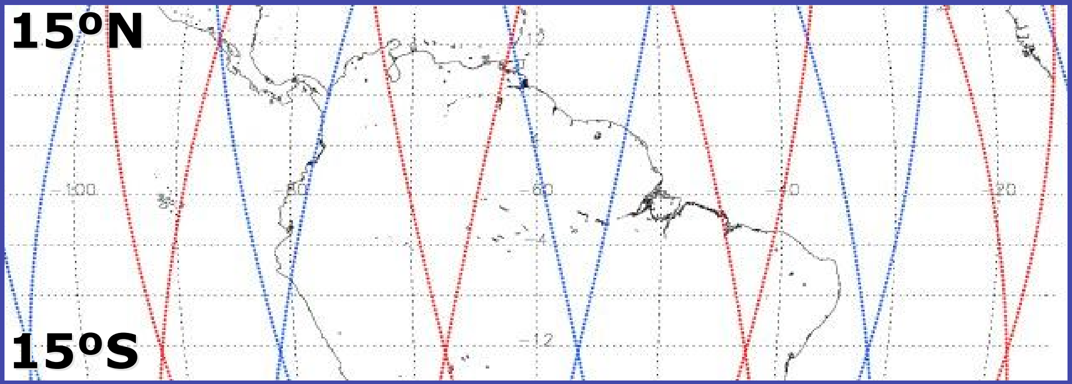
Pixel-Level Comparisons



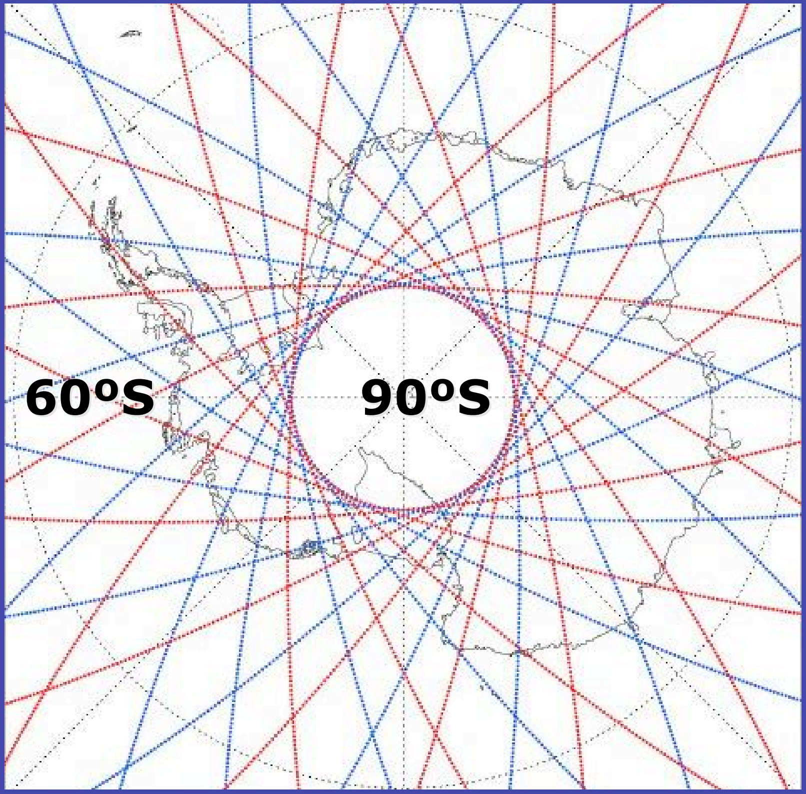


AMSR-E 37 GHz FOV (approximate)

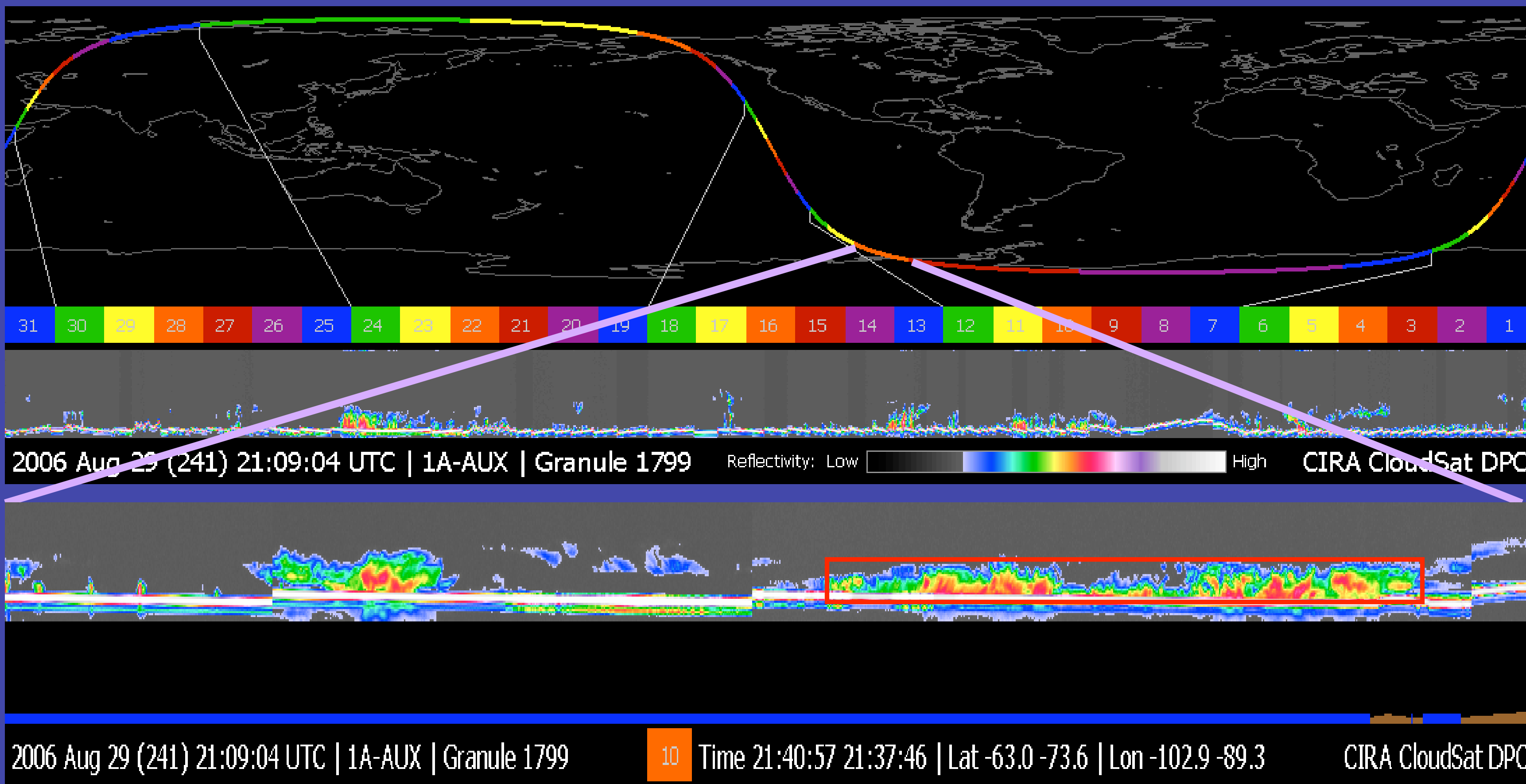
Frozen Precipitation



- CloudSat's sensitivity makes it ideal for detecting snowfall.
- The region poleward of 60º is sampled ~4 times more frequently than an equal area region at the equator!



An early look at Snowfall



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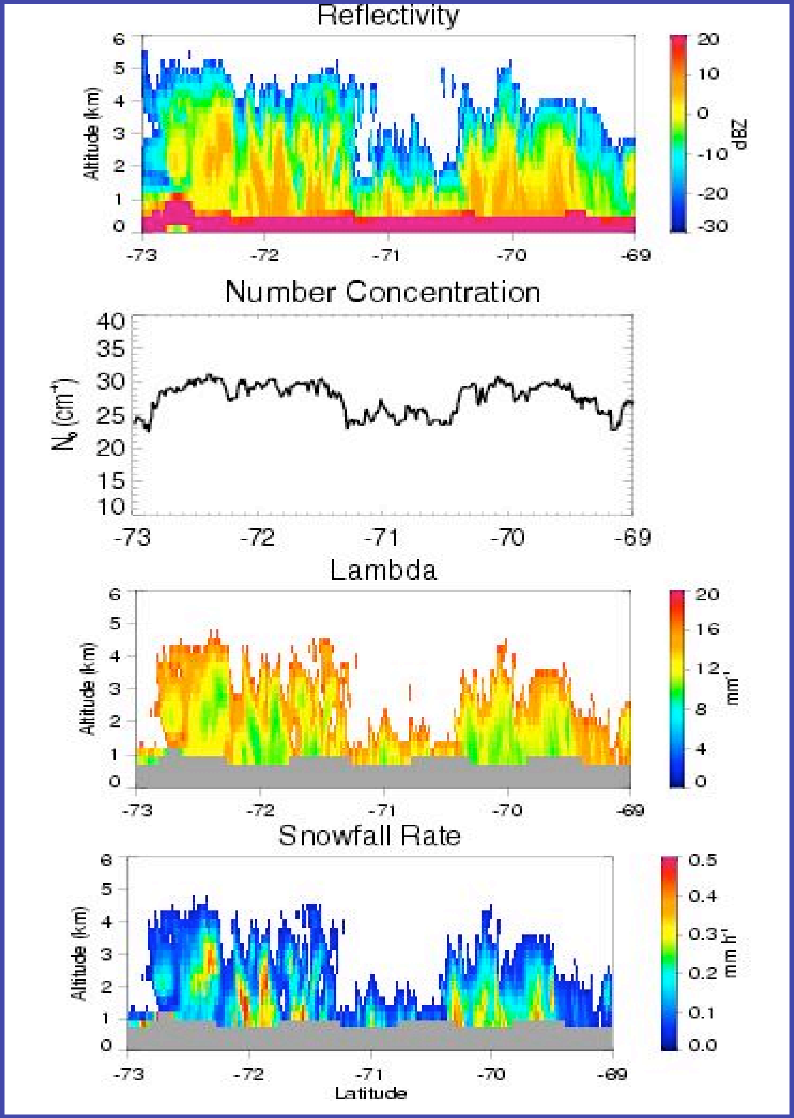
•The region poleward of 60º is sampled ~4 times more frequently than an equal area region at the equator!

Radar-Only Retrieval

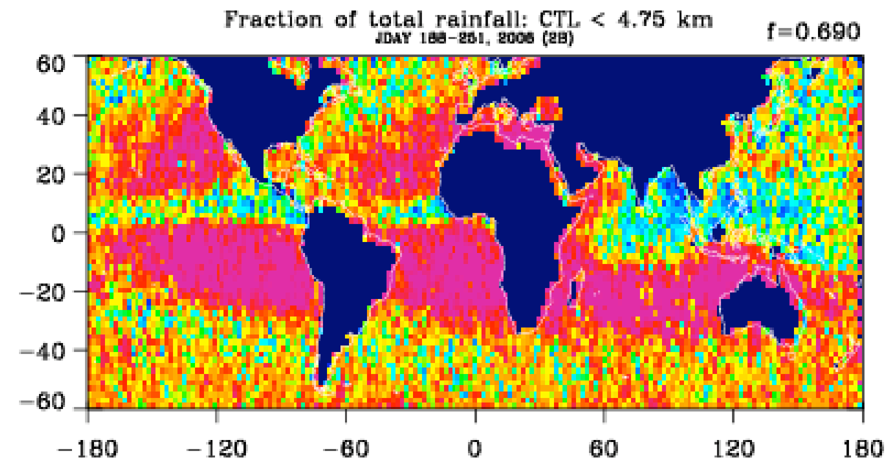
- **Very preliminary inversion of CPR reflectivities to infer snowfall rate**
- **Assumes exponential distribution of snow particles**

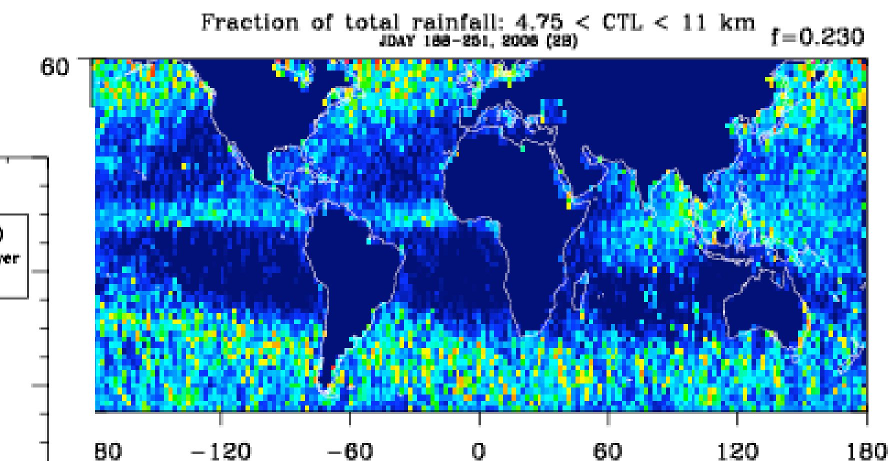
$$N(D) = N_0 \exp(-\Lambda D)$$

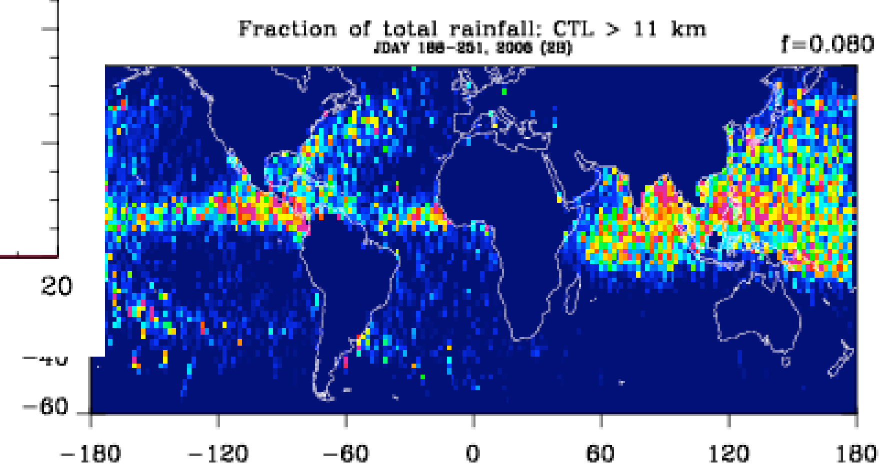
- **Similar probabilistic retrieval framework as rainfall retrieval**
- **First goal is detection and discrimination from light rainfall**

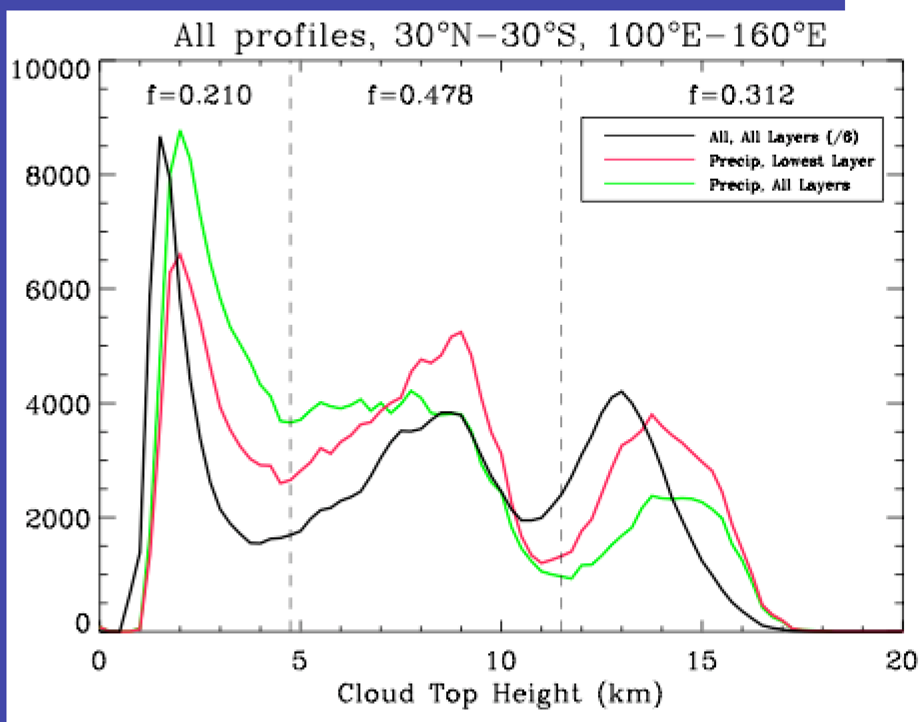


We are just beginning to quantify the properties of precipitation as a function of cloud





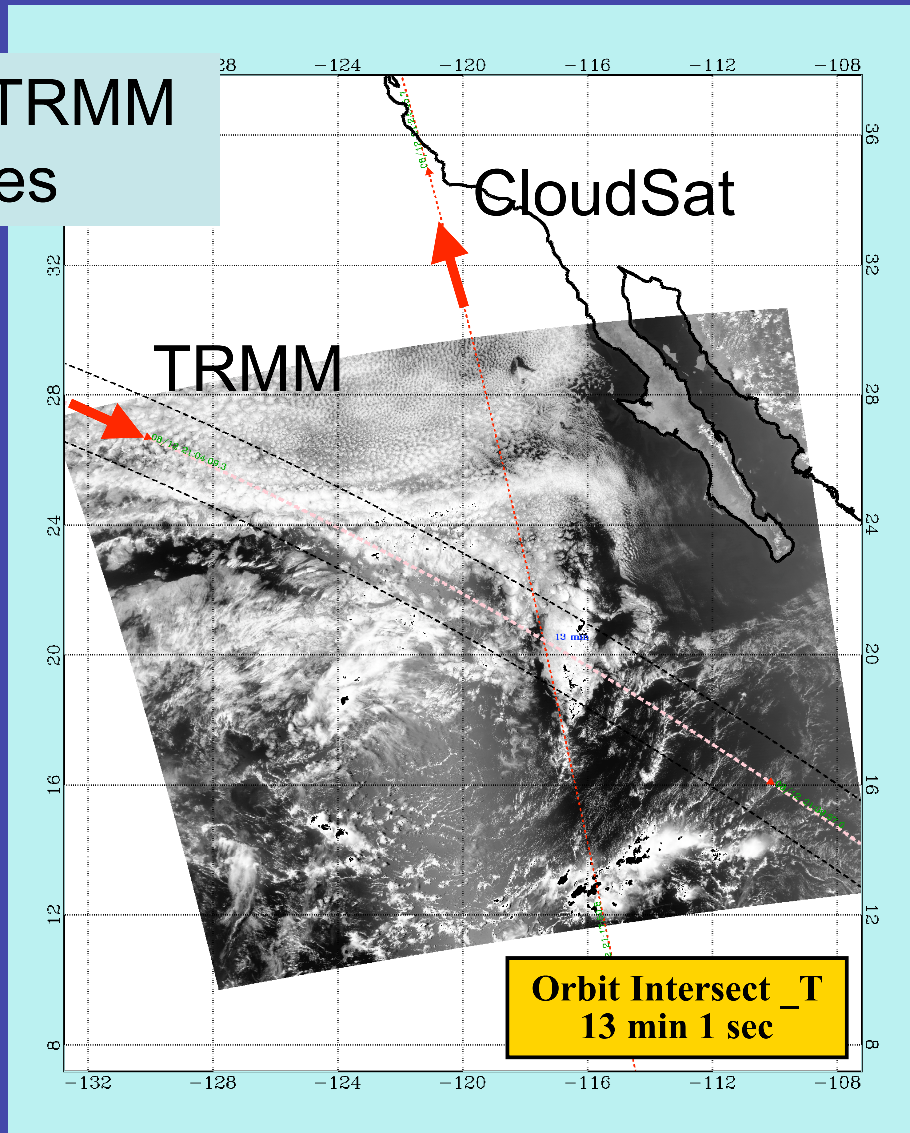




PIA based results

AQUA-MODIS (500 m/band 4-green)
August 12 (day 224) : 202534 UTC (~1226 MST)
(CloudSat orbit 01551)

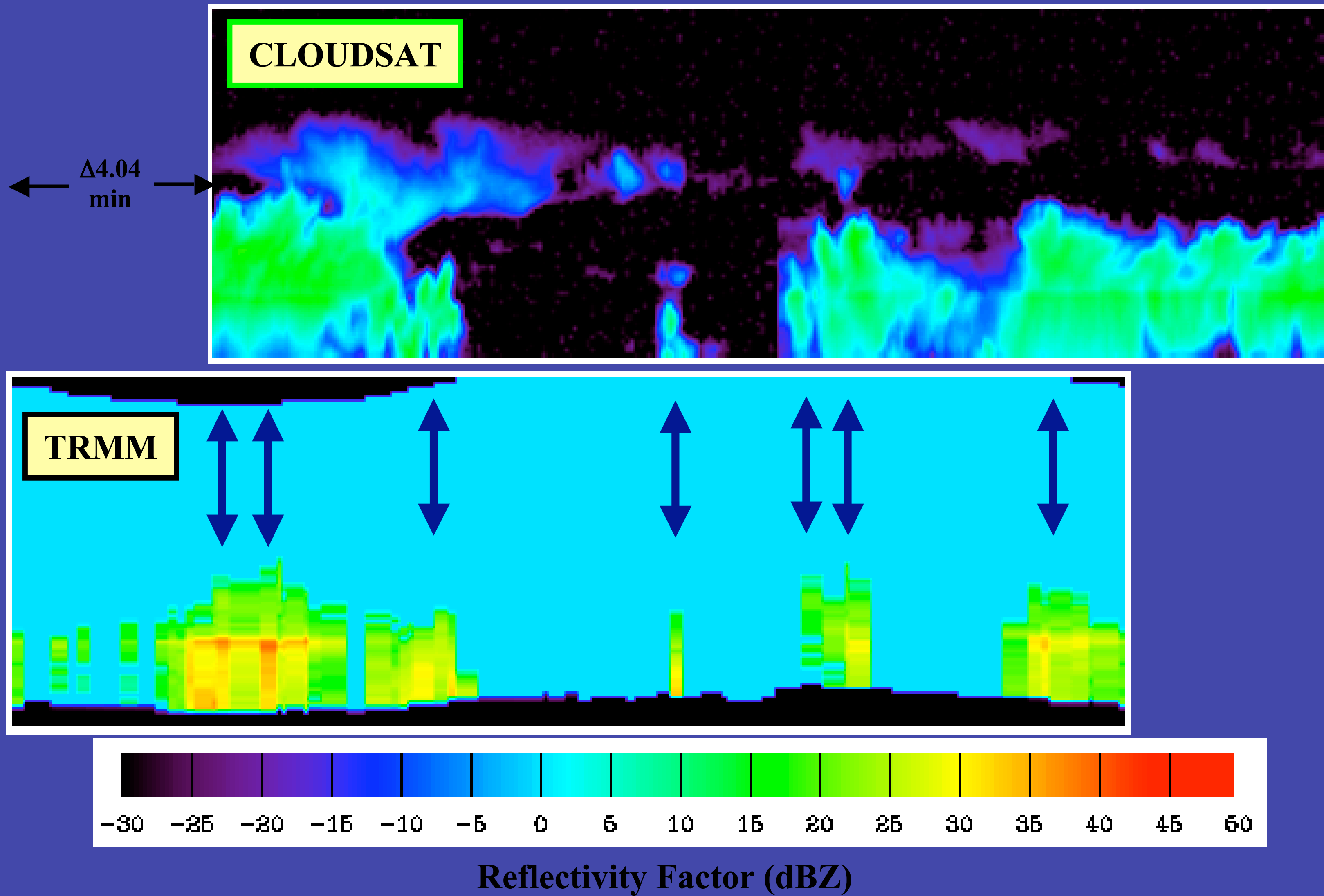
CloudSat-TRMM matches



CloudSat is supporting the development of TRMM matched data base

Courtesy, Eric Smith

Comparison of CLOUDSAT Down-track to TRMM Slant Cross-track
[25 July 2006 / ~2035 UTC (1235 MST): Intersect at 10.39ºN / 118.24ºW]



Final Thoughts/Comments

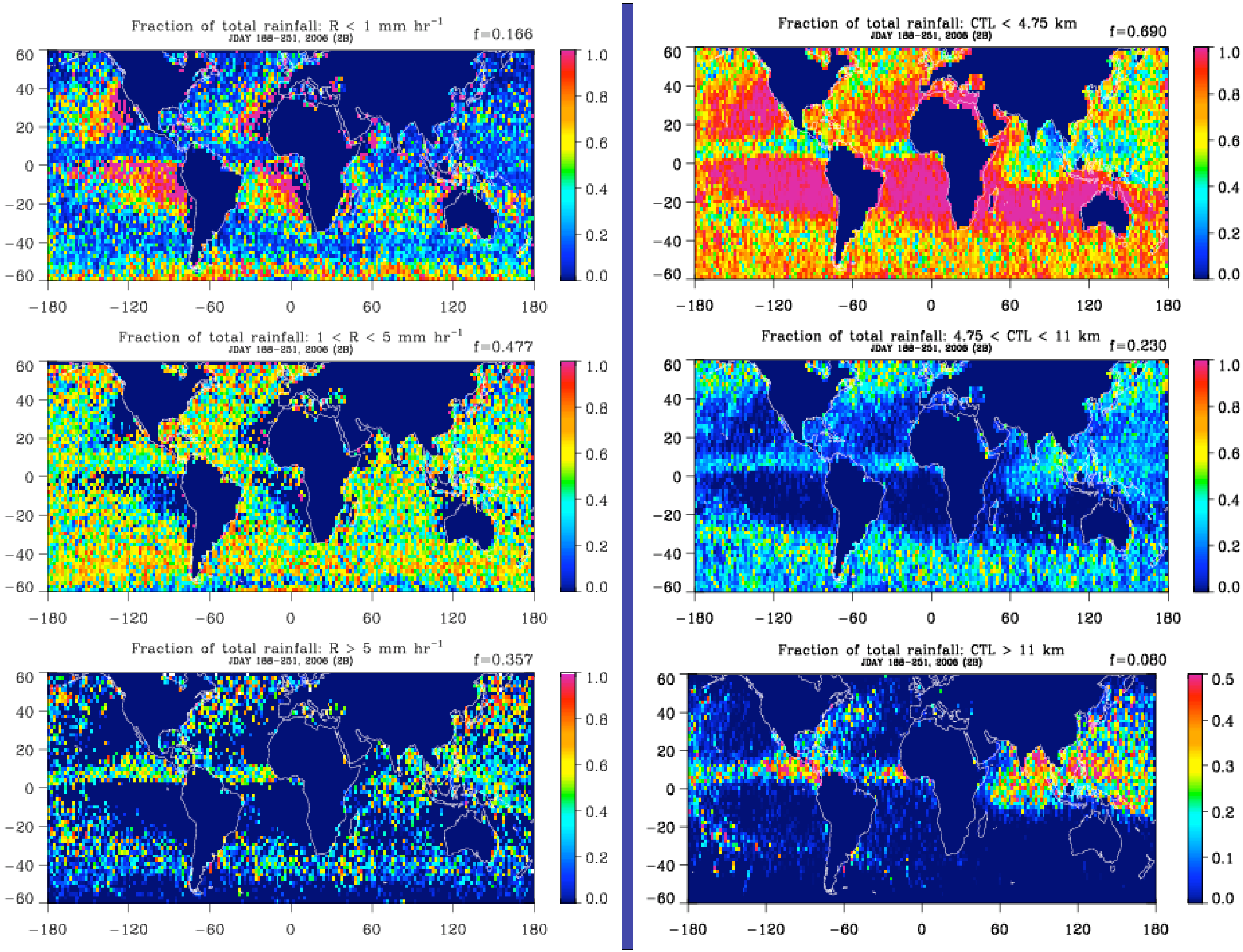
- CloudSat is literally (and figuratively) a bridge from the tropical precip measurements of TRMM to the need for global precipitation information

- CloudSat has much to offer the GPM effort, specifically during this formative stage GPM. We provide global views of precipitation that can serve as a foundation for testing an evolving the GPM observing system, of extra-tropical and polar precipitation.

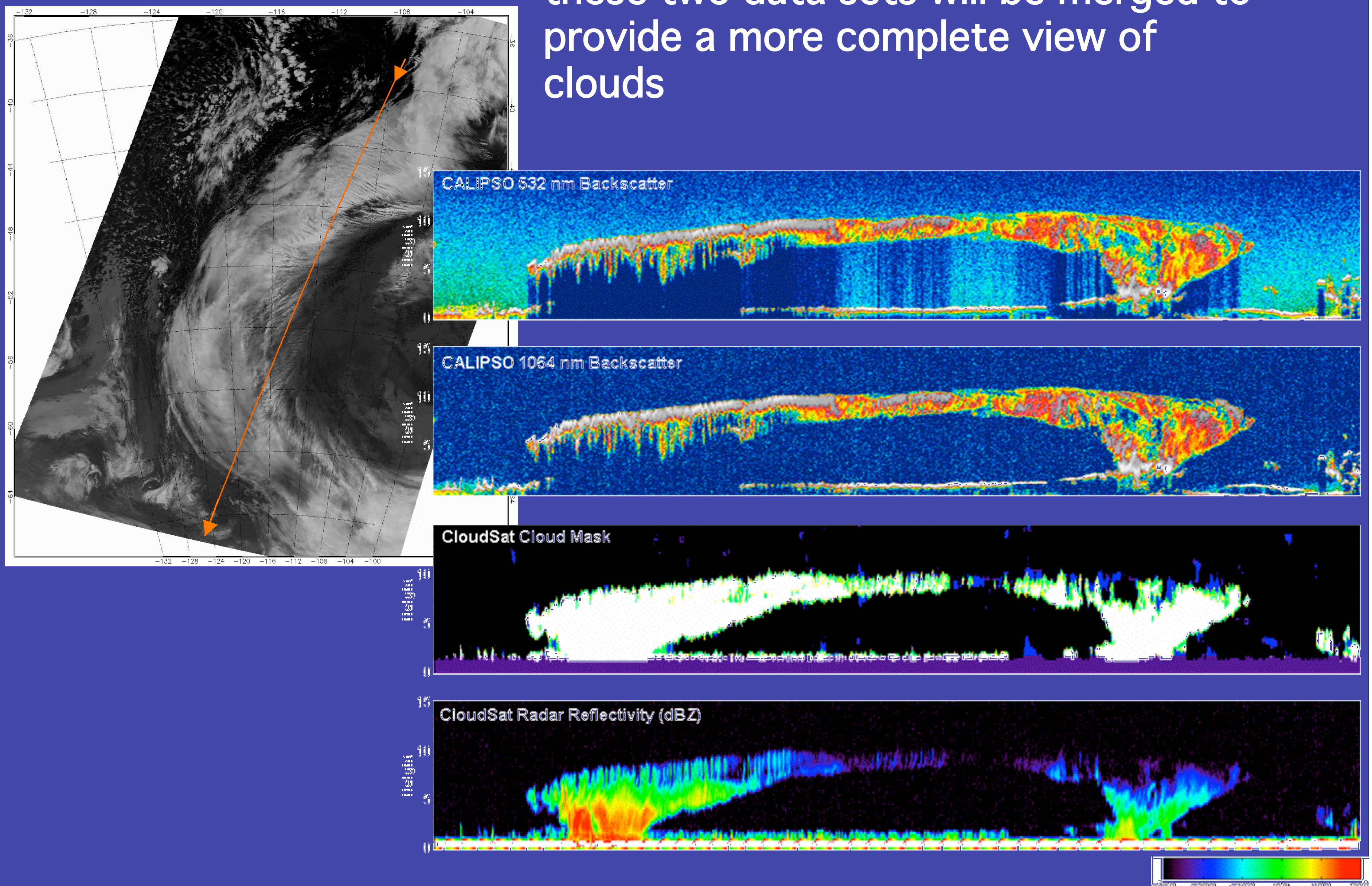
- The joint cloud and precipitation information of CloudSat offers great potential for advancing precip predictive systems.

- There is perhaps much to be gained by more formally linking the fledgling precip activities of CloudSat to GPM.

Backups


Fraction of total rainfall: R < 1 mm hr^{-1}
f=0.166
Fraction of total rainfall: 1 < R < 5 mm hr^{-1}
f=0.477
Fraction of total rainfall: R > 5 mm hr^{-1}
f=0.357
Fraction of total rainfall: CTL < 4.75 km
f=0.690
Fraction of total rainfall: 4.75 < CTL < 11 km
f=0.230
Fraction of total rainfall: CTL > 11 km
f=0.080

CloudSat - Comparison with CALIPSO - these two data sets will be merged to provide a more complete view of clouds



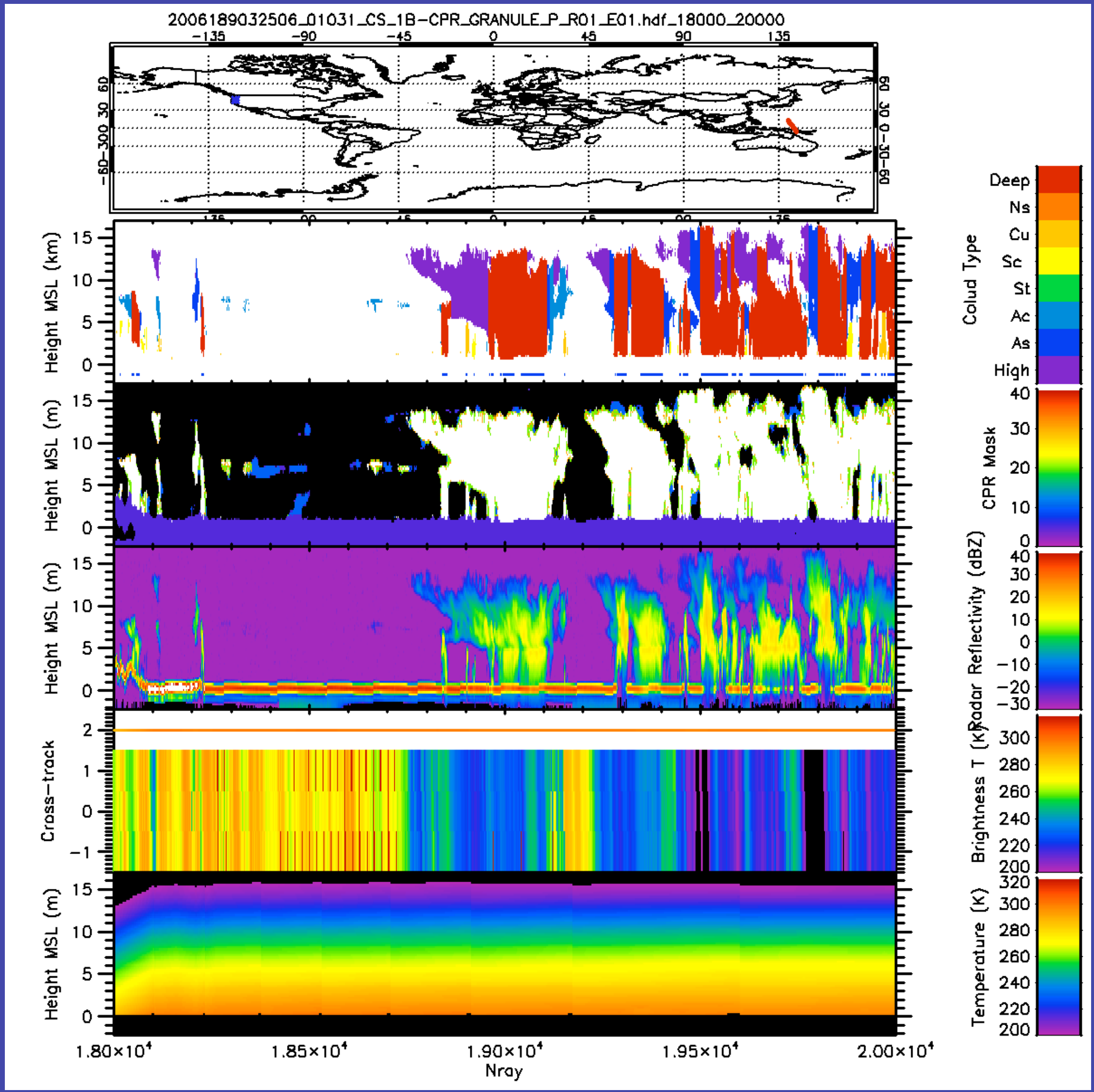
Classification (2B-CLDCLASS)

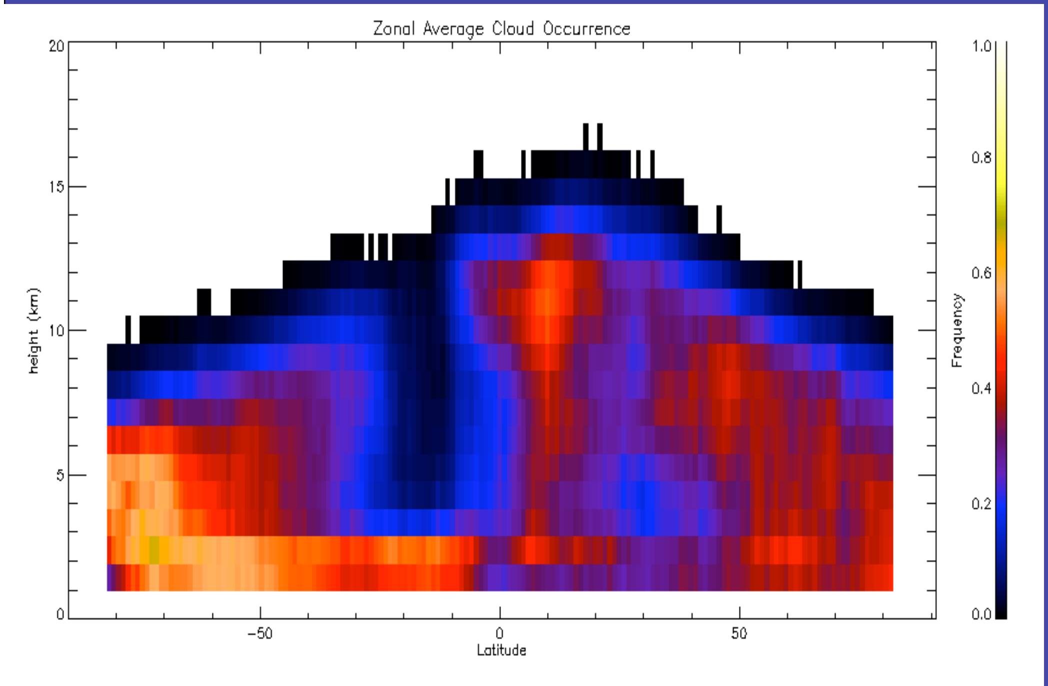
Mask (2B-GEOPROF)

Reflectivity (dBZ) (1B-CPR in 2B-geoprof)

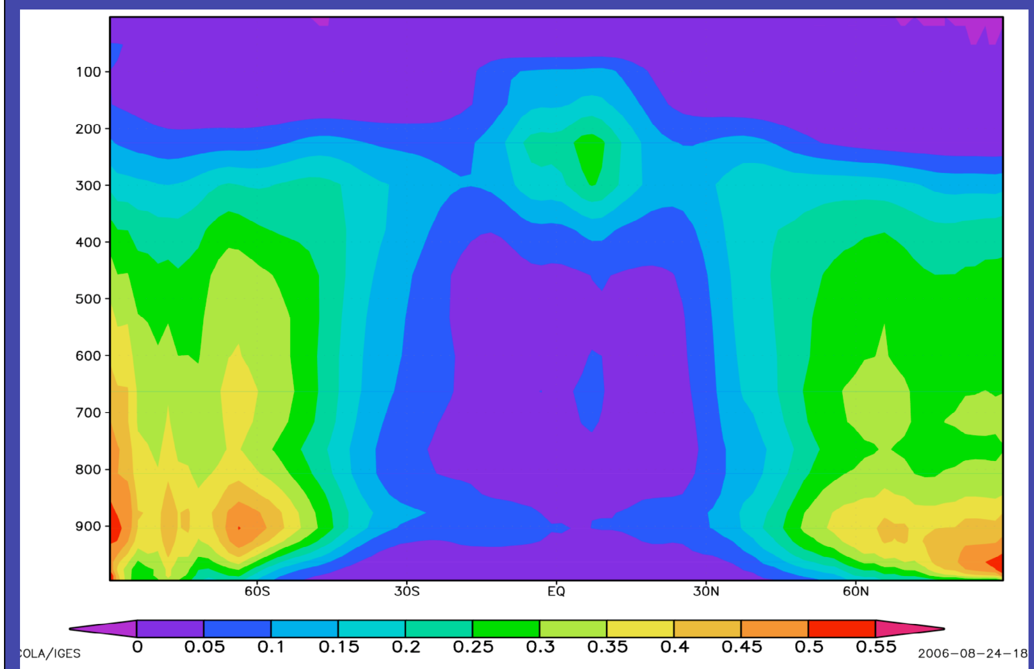
MODIS

ECMWF T(z)





July-August zonally averaged distribution of cloudiness derived from the CloudSat 2b-geoprof mask product.



JJA zonally averaged distribution of cloudiness from one of the IPCC FAR climate models- preliminary results, Mace and Klein

CloudSat Ancillary Data Sets

AN-MODIS
AN-ECMWF
AN-CALIPSO
AMSR-E
CERES

AN-MODIS: +/- 260-km swath of MODIS data

Source: NASA Goddard Space Flight Center DAAC

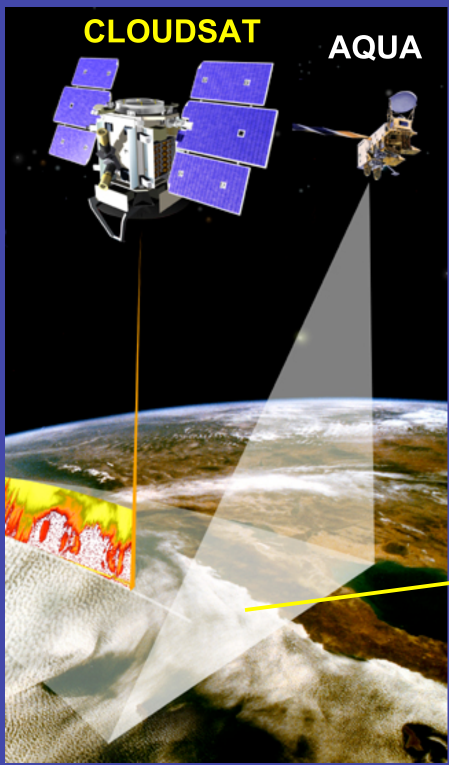
Data: *Geolocation, 22 of 36 bands, Cloud Mask*

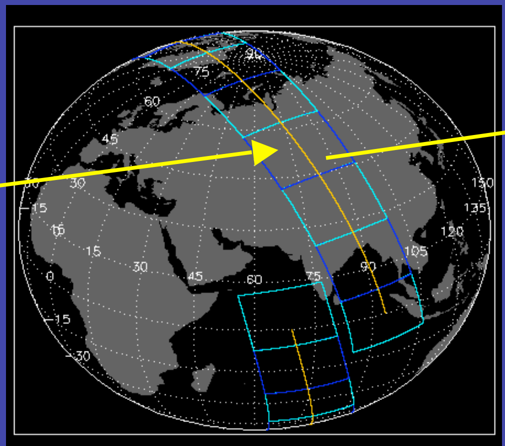
0.25 km resolution -

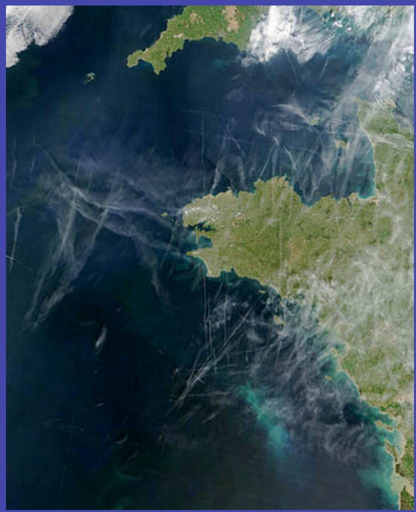
- Radiance: band 1 **(MOD02_QKM_L1B)**

1 km resolution -

- Radiance: bands 1-7, 17-20, 26-36 **(MOD02_1KM_L1B)**
- Geolocation **(MOD03)**
- Cloud Mask **(MOD35_L2)**
- Also MOD06 - cloud properties (tau, re, ctp, ….)







April 25, 2004
Contrails – NW Europe

Field Campaign Synergy

CloudSat-GPM Field Campaign Synergy

GPM Participation in the Canadian CloudSat/Calipso Validation Program (C3VP)
Winter 2006-2007

1. Hardware contributions to CloudSAT/CALIPSO validation
2. Collection of data sets for development of GPM snowfall detection and estimation algorithms

- **To** develop models **that convert** microphysical properties **(snow size, shape distributions, density, ice-air-water ratio)** to radiative properties **(asymmetry factor, absorption-scattering-backscatter coefficients)**
- **To** relate radiative properties to microwave radiances and radar reflectivities **observed by GPM instruments**
- **To combine satellite, aircraft and ground measurements for GPM** GMI and DPR algorithm validation
- **To** support Cloud-Resolving Model (CRM) **microphysics validation in cold-region simulations**

3. Further support ongoing EarthCARE-GPM satellite simulator algorithm collaboration

- **Development of** fully coupled, physically-based modeling system **including land-surface, atmosphere, precipitation and radiative transfer simulations/interactions**

GPM-Provided Instrumentati

- UMass Advanced Multi-Frequency Radar (AMFR) – January 2007

1. Ku/Ka/W bands
2. Matched 0.7º beams
3. Antenna scans at 1º sec^{-1} from 0° to 90° in elevation and ±135° in azimuth

- GSFC Parsivels – November 2006 through February 2007
  - *Measures hydrometeor numbers, sizes (maximum width), type, and fall speeds*

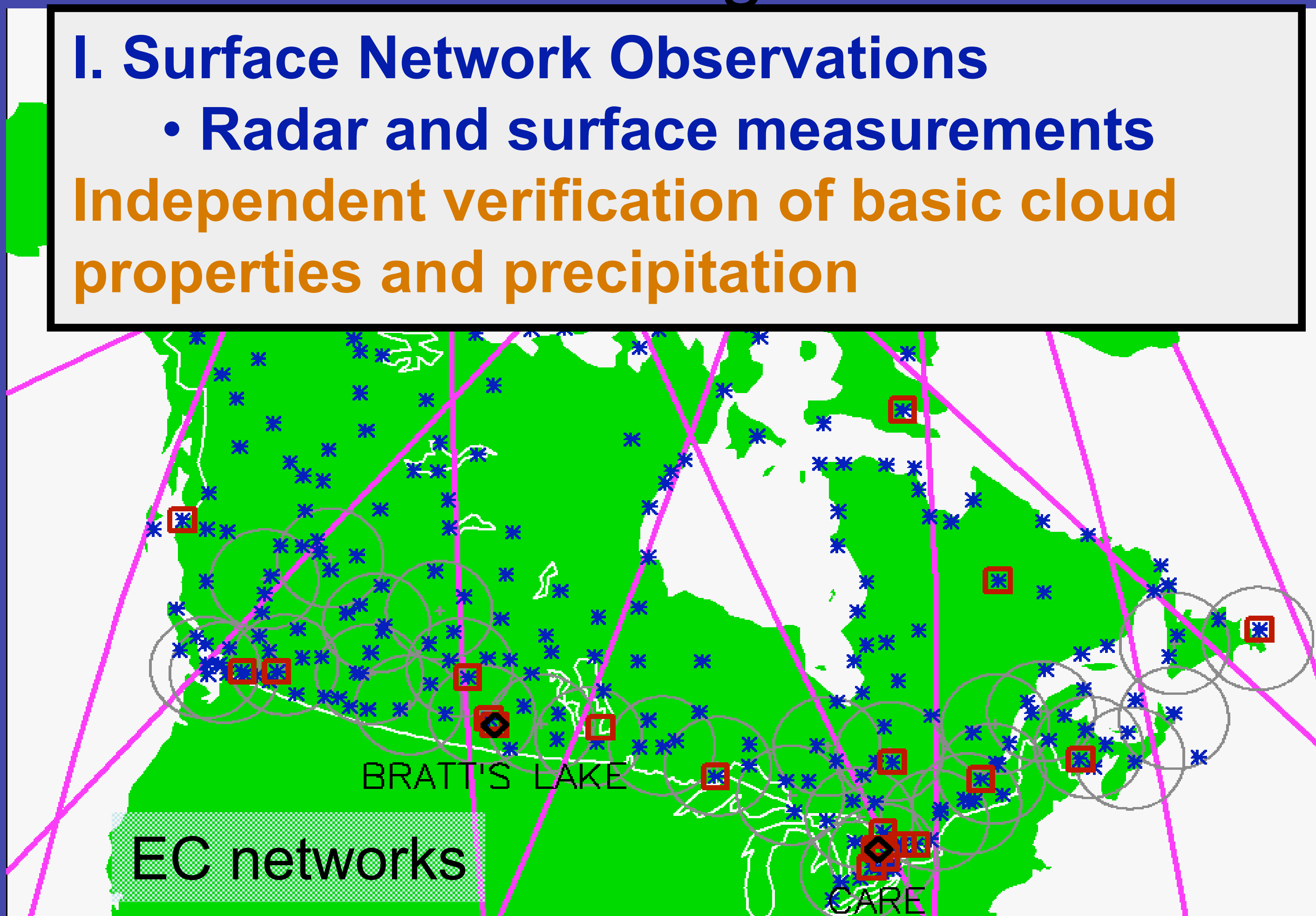
- 2D Video Disdrometers (Colorado State U.) - Jan. 2007
  - *Measures hydrometeor concentrations, sizes (equivalent diameter), shapes, and fall speeds*

The Canadian surface observation network and CloudSat ground tracks for a

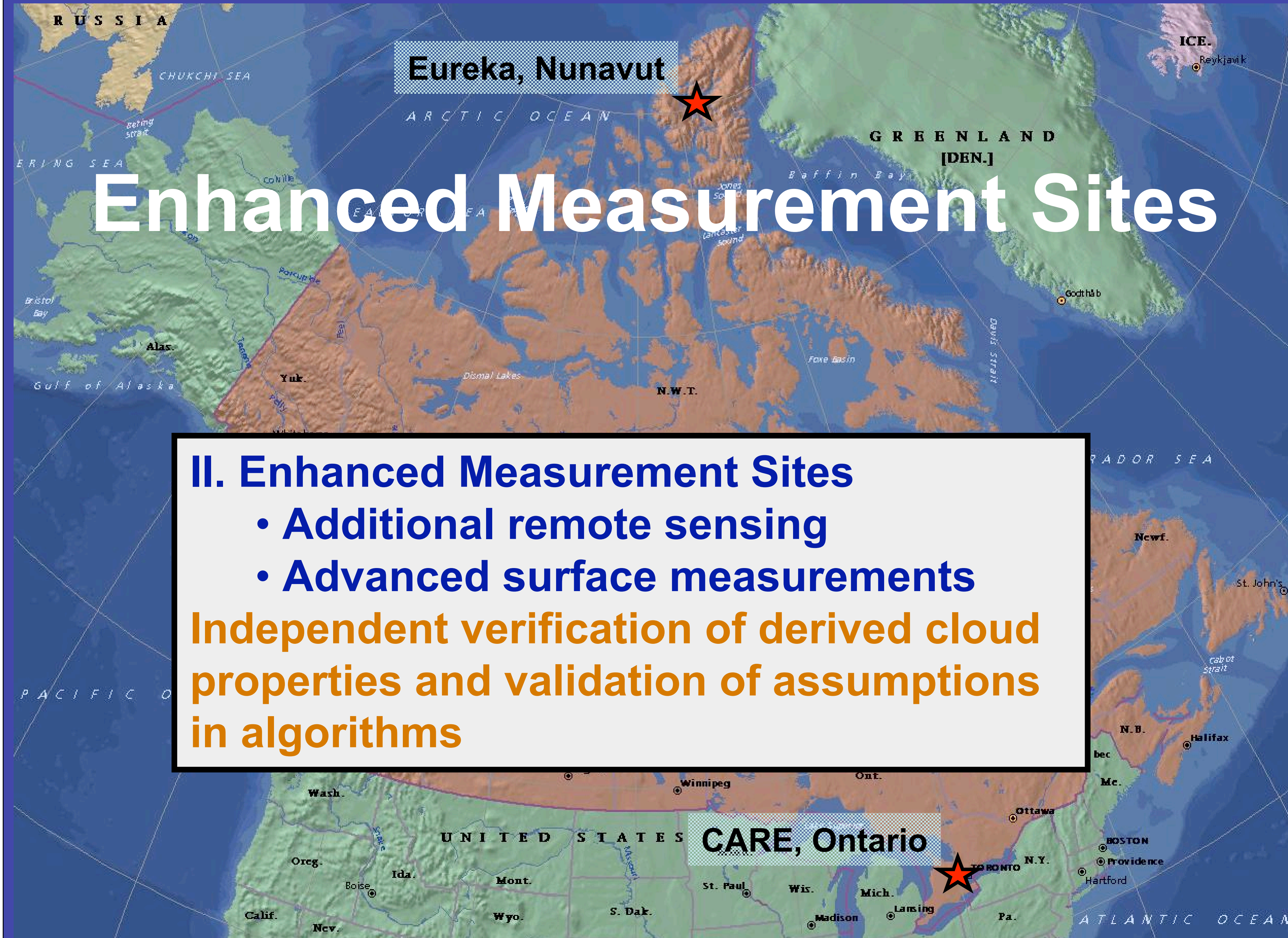
I. Surface Network Observations

- **Radar and surface measurements**

Independent verification of basic cloud properties and precipitation



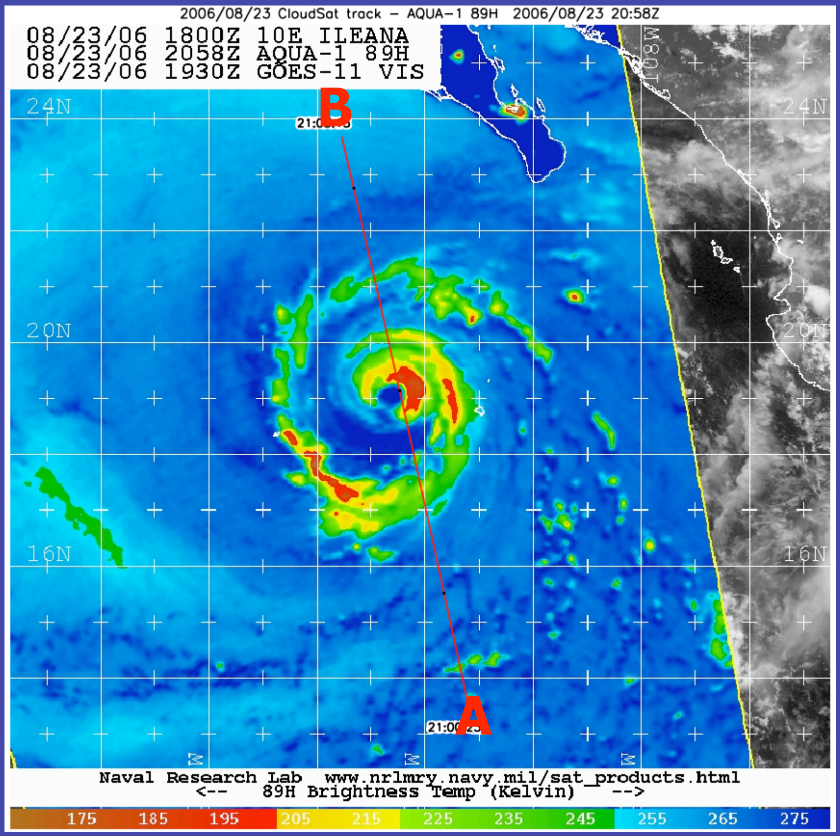
Enhanced Measurement Sites



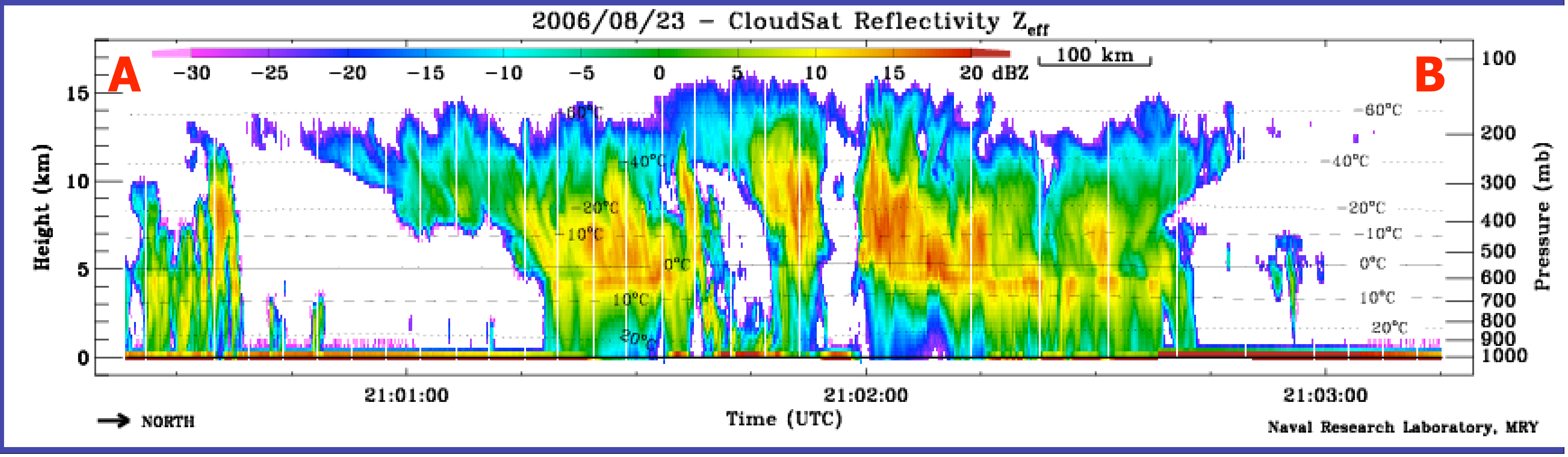
II. Enhanced Measurement Sites

- Additional remote sensing
- Advanced surface measurements

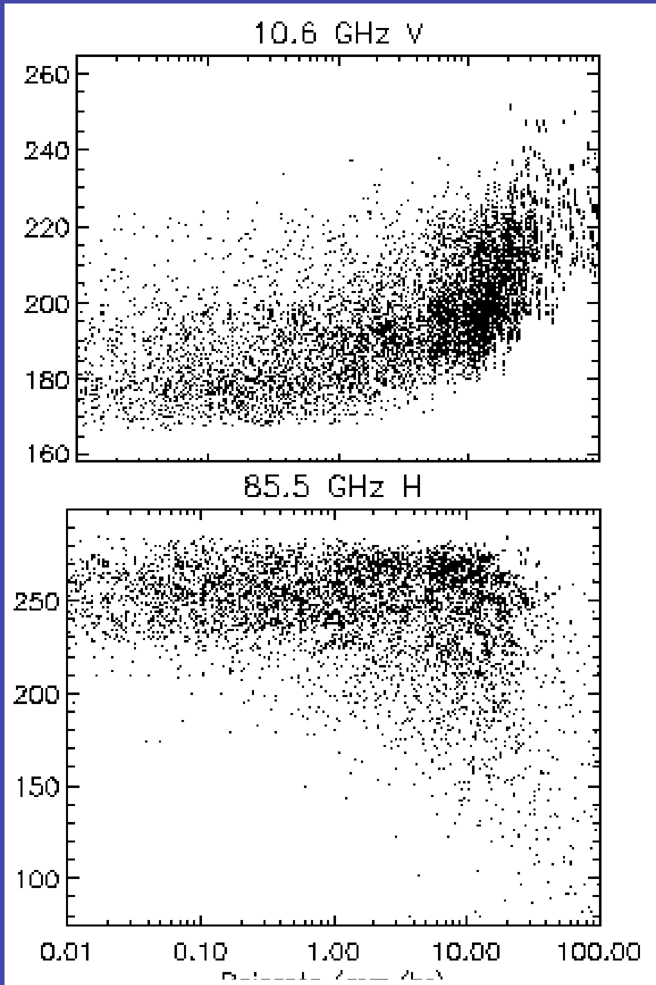
Independent verification of derived cloud properties and validation of assumptions in algorithms


2006/08/23 CloudSat track – AQUA-1 89H 2006/08/23 20:58Z
08/23/06 1800Z 10E ILEANA
08/23/06 2058Z AQUA-1 89H
08/23/06 1930Z GOES-11 VIS
B
A
24N
20N
16N
Naval Research Lab www.nrlmry.navy.mil/sat_products.html
<-- 89H Brightness Temp (Kelvin) -->
175 185 195 205 215 225 235 245 255 265 275

ILEANA

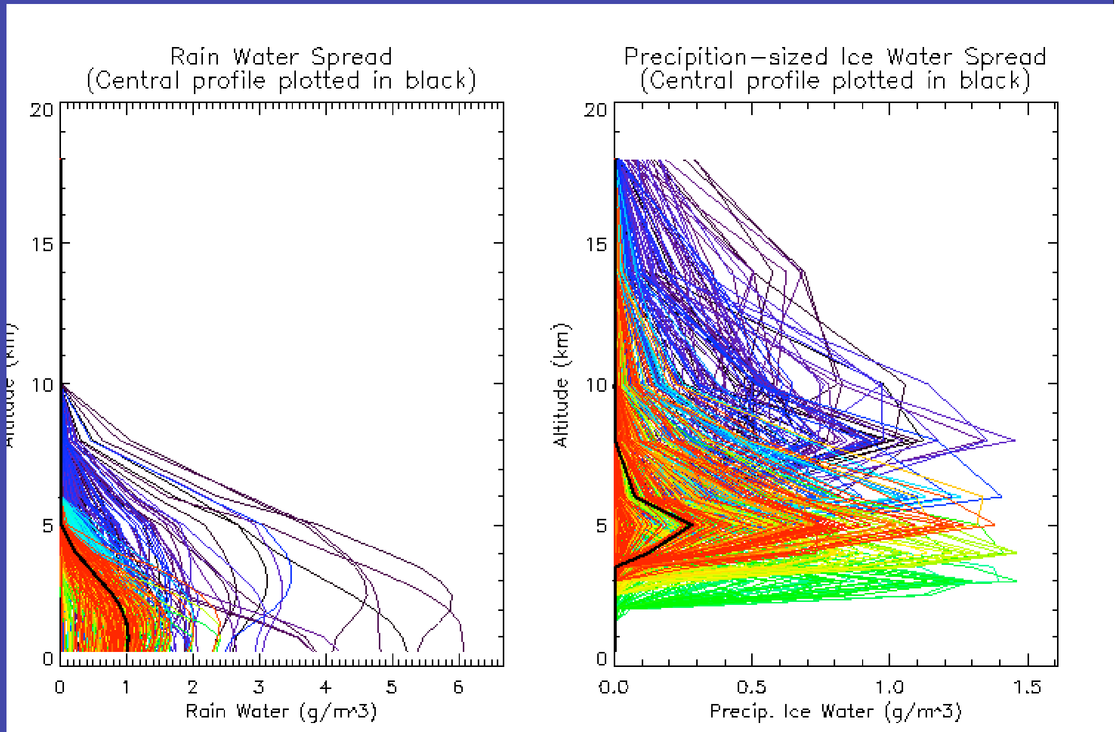

2006/08/23 – CloudSat Reflectivity Z_eff
A
B
−30 −25 −20 −15 −10 −5 0 5 10 15 20 dBZ
100 km
Height (km)
Pressure (mb)
Time (UTC)
21:01:00
21:02:00
21:03:00
NORTH
Naval Research Laboratory, MRY

GPM on clouds
1. Microwave Radiances

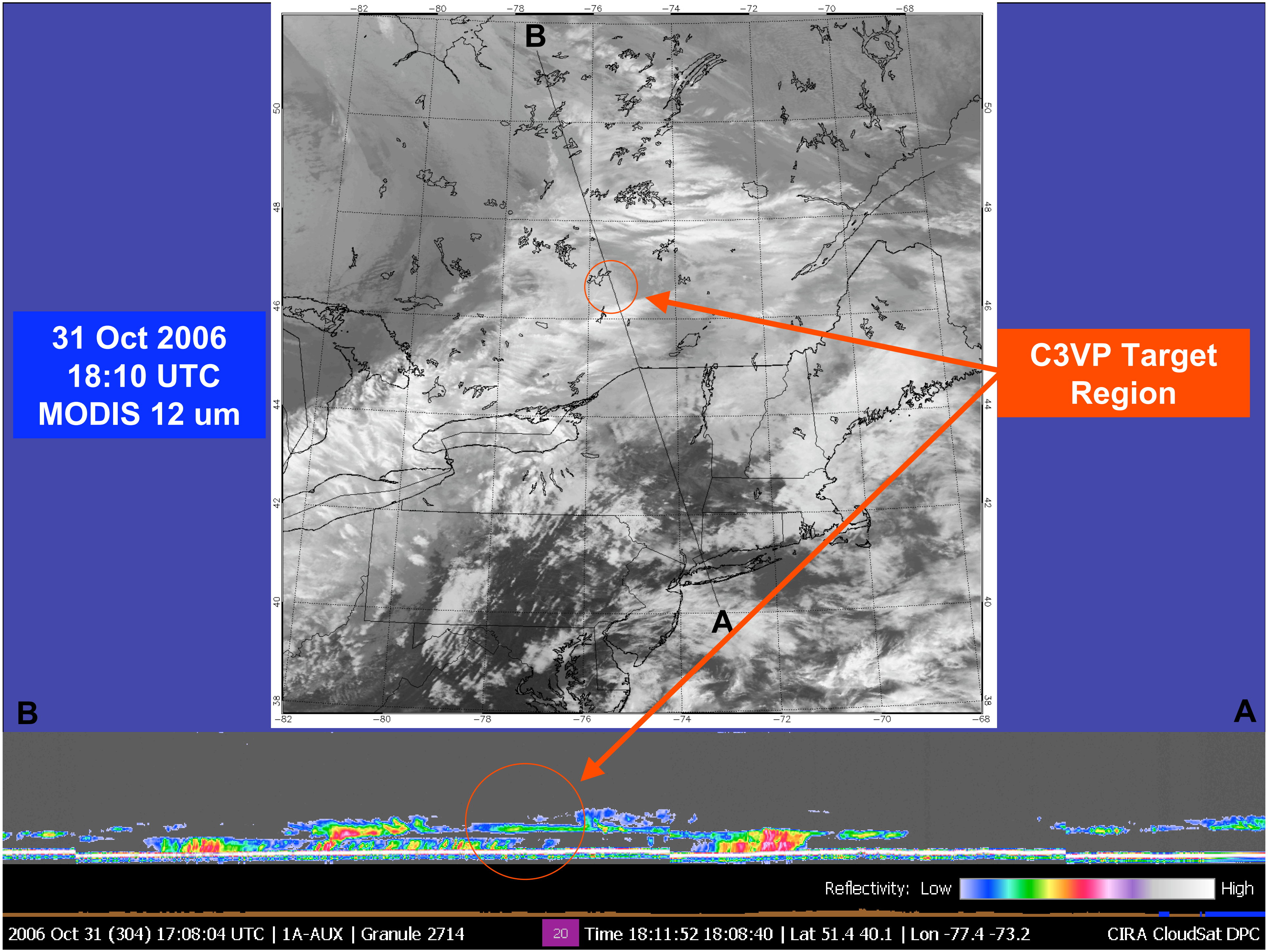


rainrate (mm/hr)

These profiles correspond to different rain rates but 'same' microwave Tb



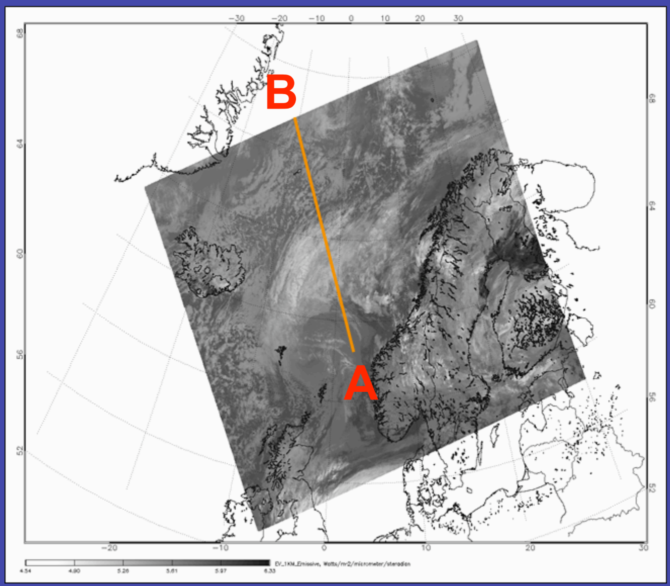
Microwave radiance ambiguity to a large part influenced by cloud profile



31 Oct 2006
18:10 UTC
MODIS 12 um
C3VP Target Region
B
A
Reflectivity: Low
High
2006 Oct 31 (304) 17:08:04 UTC | 1A-AUX | Granule 2714
20
Time 18:11:52 18:08:40 | Lat 51.4 40.1 | Lon -77.4 -73.2
CIRA CloudSat DPC

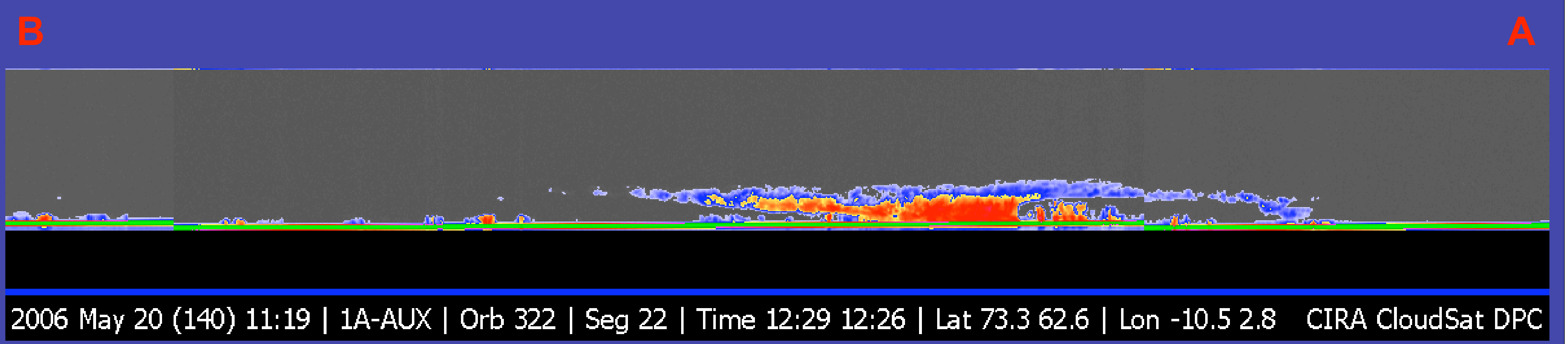
CloudSat - FIRST IMAGE

This segment was the first dump of CloudSat data - 20 May 2006 12:26-12:29 UTC



Location of CloudSat data segment on a 5-minute MODIS infrared (10.8μ) data swath.
(approx. 25 minutes prior to CloudSat overpass)

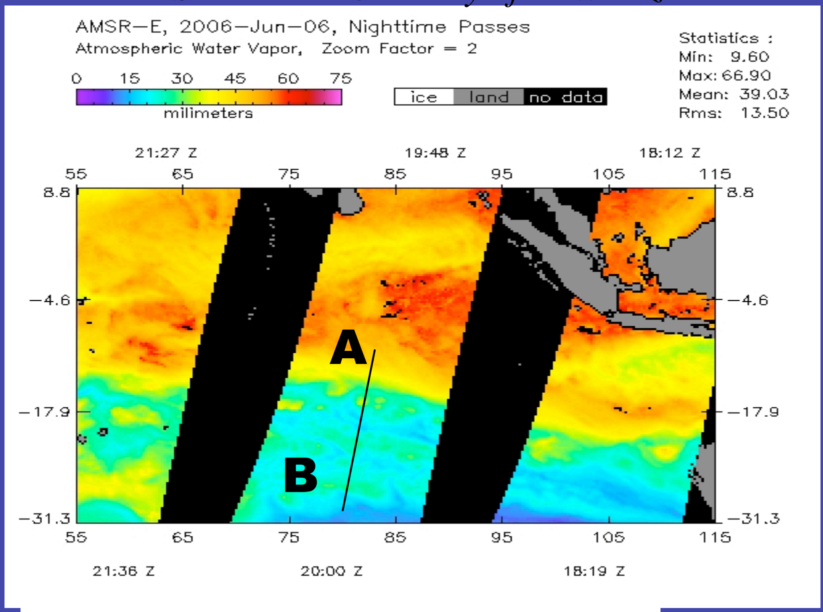
(MODIS image downloaded from Goddard DAAC)

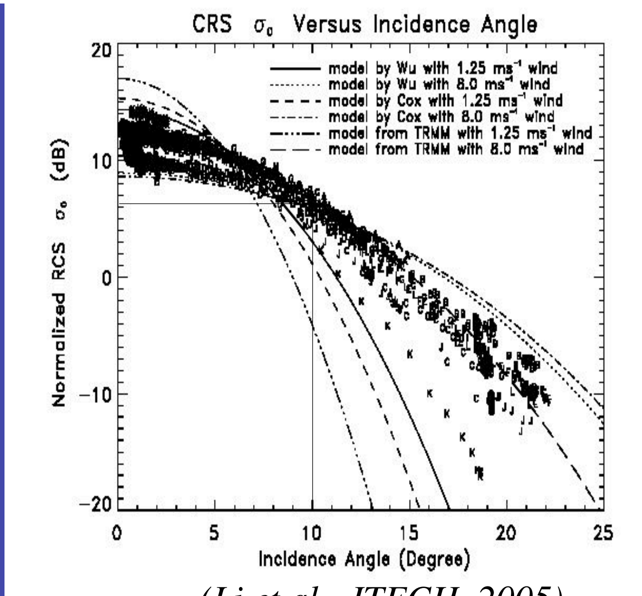


Preliminary Assessment on Calibration Using Cloud-free Ocean Returns

- Calibration Accuracy Requirement: 2 dB (3-σ)
- Pre-launch estimates: 1.7 dB (3-σ)
- June 6 Calibration Exercise:
  - CPR initial estimate of cloud-free sea surface NRCS at 10˚ incidence (w/o atmospheric correction): -2 to +2 dB
  - AQUA AMSR-E: 20 to 45 mm of water vapor estimates
    - Corresponding 2-way attenuation at 94 GHz: 2.5 to 5.5 dB
  - After water vapor correction and Doppler correction, sea surface NRCS at 10˚ incidence: 5 to 6.5 dB
    - They appear to be consistent with published airborne radar results
- Calibration will be an on-going effort
  - Monthly calibration exercises
  - Nadir clear-ocean NRCS statistics
  - Ground-based and airborne field campaigns

AMSR-E data: Courtesy of F. Wentz





(Li et al., JTECH, 2005)

Validation

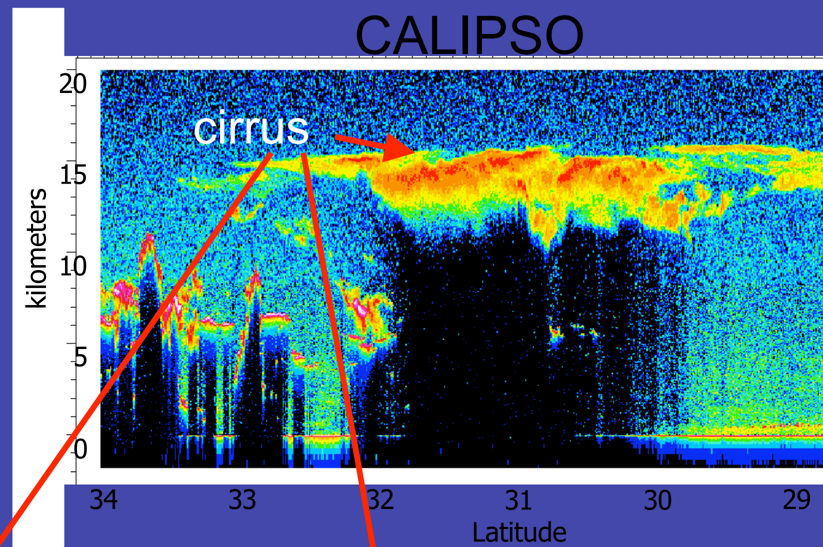
Validation is ongoing - an example of a focused val experiment conducted Jul 26 - Aug 14, 2006 primarily to examine the operation of the spaceborne active sensors

August 12 Flight Comparison
(focus on CALIPSO) FL

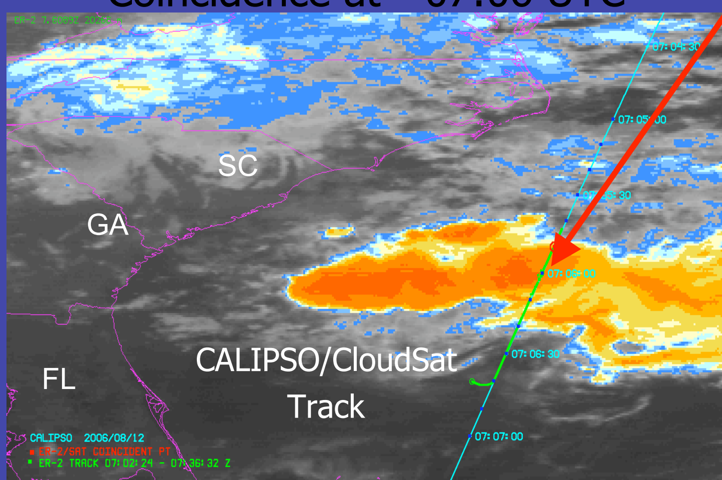
Flight Objectives

- verify lidar calibration over thick cirrus layer at night
- verify 1064 and 532 sensitivities with complex cloud & aerosol scenes

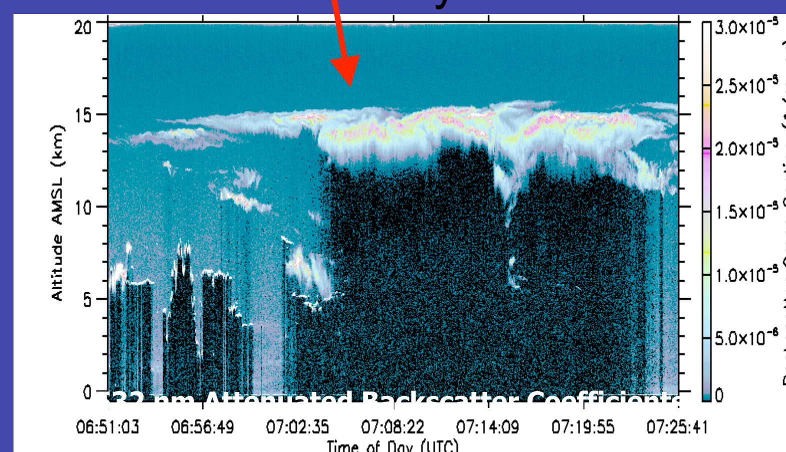
CALIPSO



GOES Image
Coincidence at ~07:06 UTC

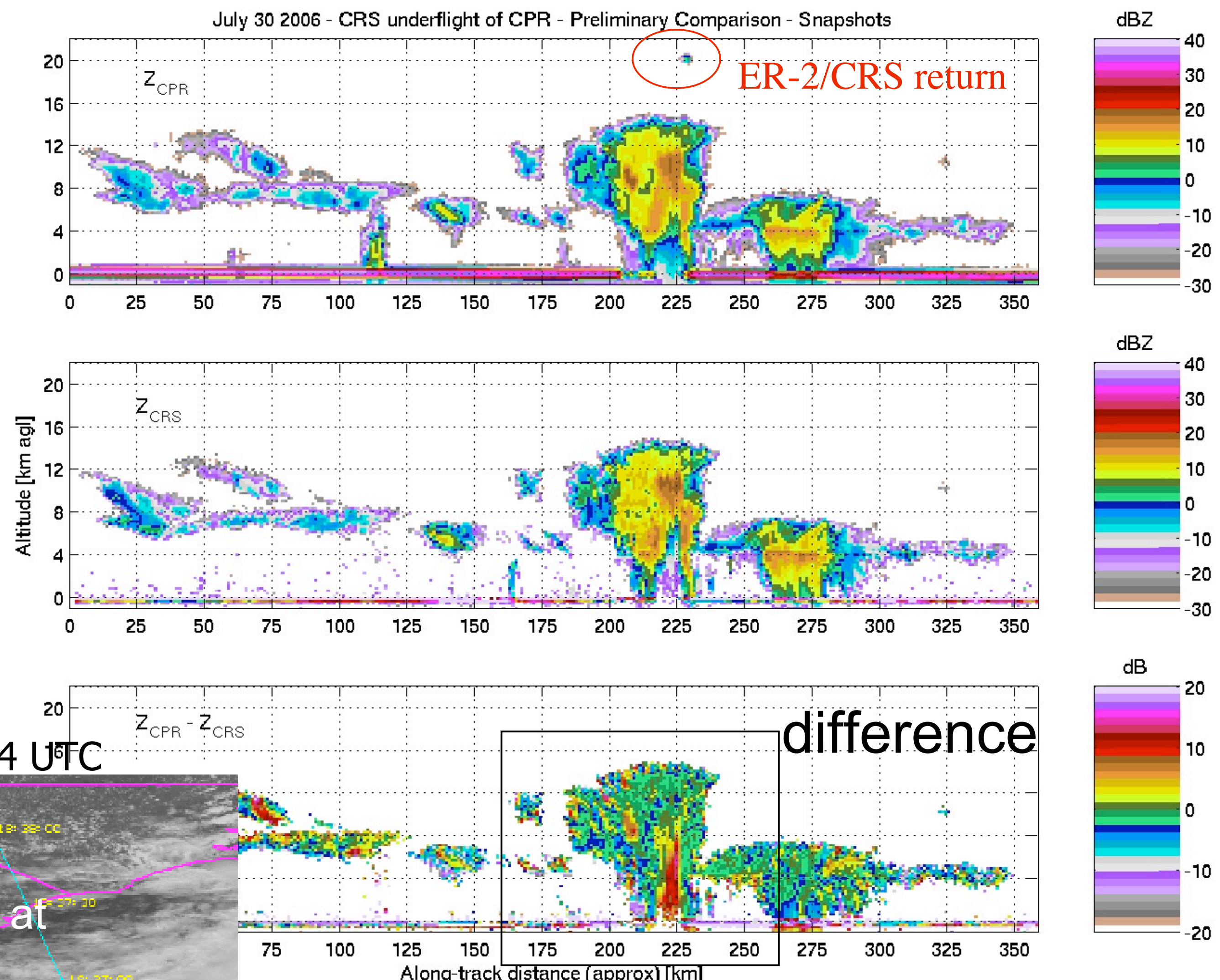


ER2 Cloud Physics Lidar

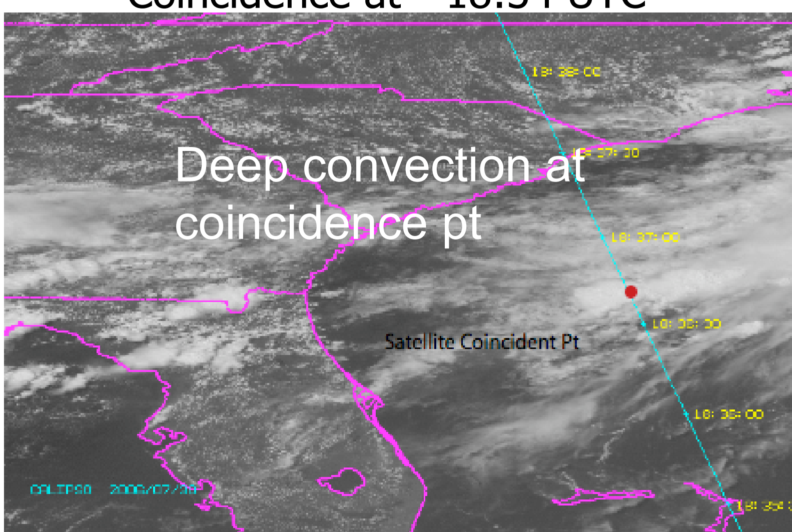


532 nm Attenuated Backscatter Coefficients

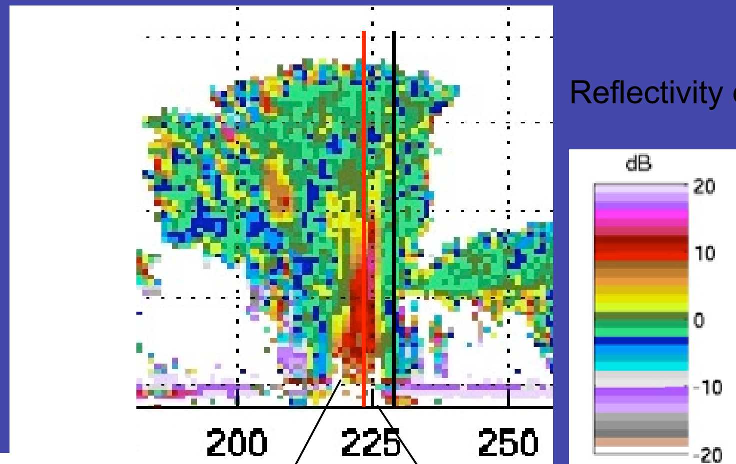
July 30 Flight Comparison *(cloudsat)*



GOES Image
Coincidence at ~18:34 UTC



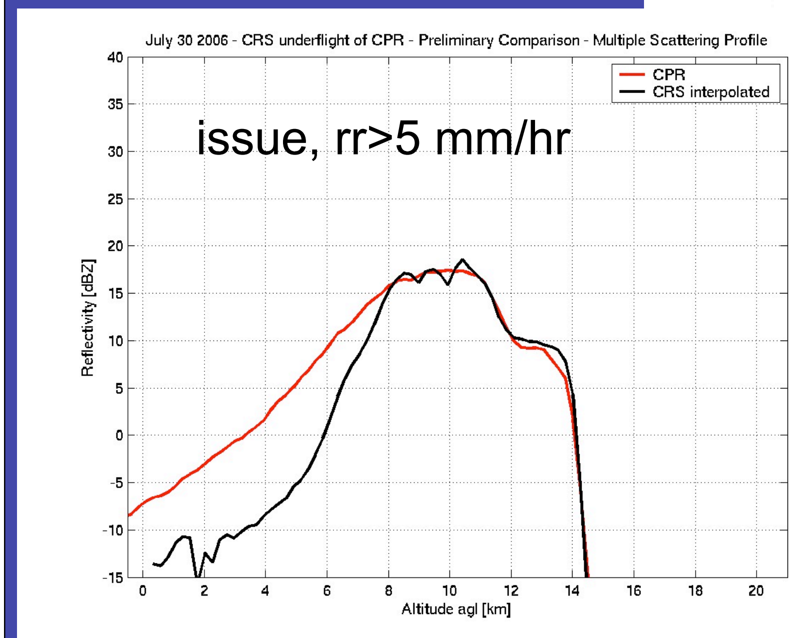
CPR/CRS Co-located Profiles

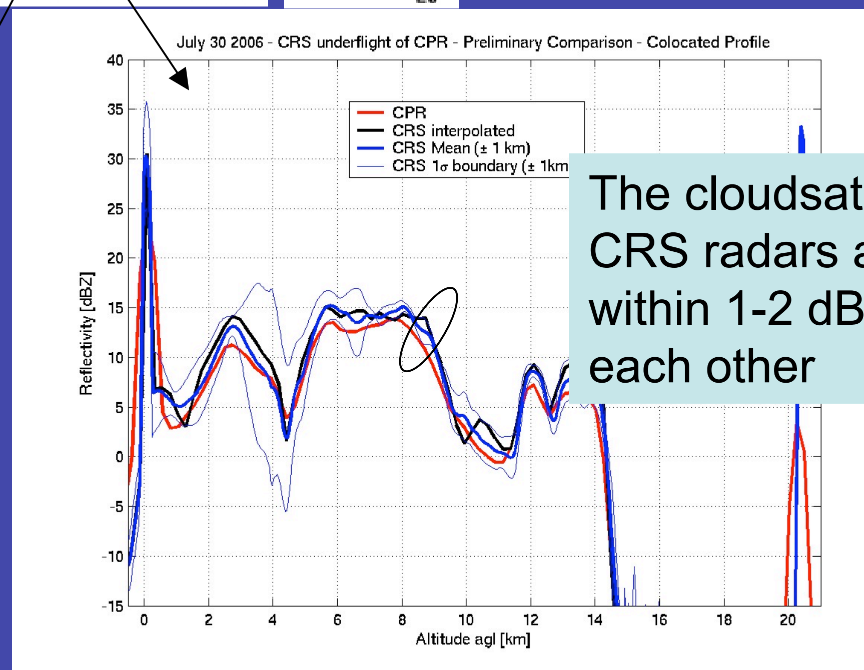


Reflectivity differnce

Multiple scattering

No multiple scattering





The cloudsat and CRS radars are within 1-2 dBZ of each other

Profile comparisons in region of heavy preciptation - differences indicator of multiple scattering effects of spaceborne radar signals by heavy precipitation

Profile comparisons outside precipitation and at time of detection of ER2 confirms CPR operations

Making the link between cloud and precipitation makes sense because:

- Science demands it
- Advanced (and future) predictive model systems are approaching it
- And mother nature works that way

So can a cloud mission (ie. CloudSat) that 'does a little precipitation' significantly contribute toward the aspirations of a precipitation mission that 'does a little cloud' ????

YES and furthermore there are exciting opportunities and mutual benefits for both of us